EMERGENCY WATER SUPPLIES

TO

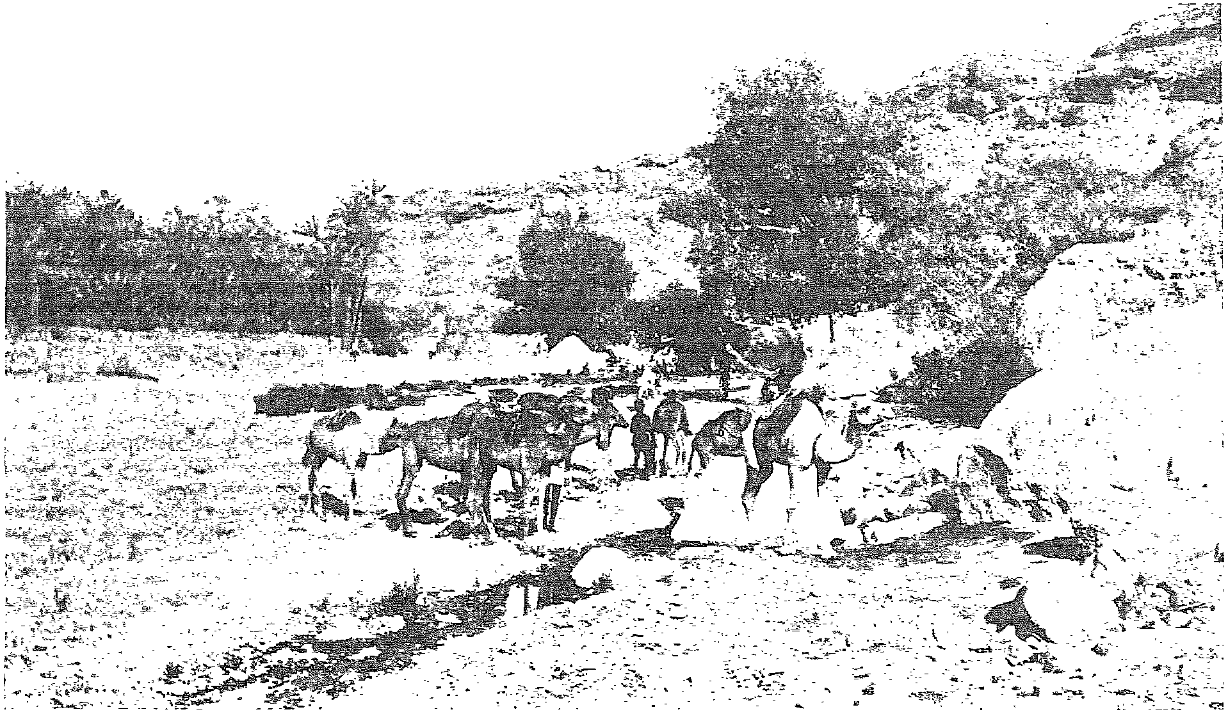
MAJOR-GENERAL SIR HUBERT A. LIVINGSTONE,
R.E., K.C.M.G., C.B.

AND

THE R.E. OFFICERS WITH THE MEDITERRANEAN
EXPEDITIONARY FORCES

THIS VOLUME IS
DEDICATED

AS A MARK OF REGARD AND APPRECIATION OF THE
KINDNESS AND CONSIDERATION RECEIVED
FROM ALL UNDER TRYING
CIRCUMSTANCES



[Frontispiece.

SCENE AT A SPRING IN A NEARLY WATERLESS PART OF THE HADRAMAUT, ARABIA.

EMERGENCY WATER SUPPLIES

FOR MILITARY, AGRICULTURAL, AND COLONIAL PURPOSES

Based on Experience of the Mediterranean Expeditionary Force Operations, with Special Reference to the use of Drive Tube Wells and Drilling

BY

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PREFACE

THE present volume is essentially a description of the operations undertaken for the supply of water to the Armies, operating in the Middle East during the European conflict, and the Macedonian data are extracted almost verbatim from the Author's official report to the War Office. As circumstances prevented its official publication, authority was given to publish the information privately. Exceptional opportunities were afforded for continuous and close study of highly diversified water problems, upon the solution of which the health of troops and animals often depended, as well as the strategy of commanders.

Between the years 1915 and 1918 water projects in large numbers were undertaken in Gallipoli and the neighbouring Grecian islands, Salonika and Macedonia, Greece and Serbia, and investigations of absorbing interest were conducted in Palestine, Sinai, Arabia, including Aden, Somaliland, and the Sudan. Technical assistance was also rendered to the French, Serbian, Italian, and Greek Armies. Never in the world's history had there been such urgent need for developing emergency water supplies as during the war, and one of the surprises was the extent to which tube wells could be employed and large supplies of water rendered available at a few hours' notice. It is this rather neglected and, perhaps, disdained feature of water supply work that has been specially developed in this work.

In order to round off the subject, the principles guiding water prospecting are briefly dealt with, but the book is in no sense intended as a text-book on hydrology, but a record of actual achievements that should aid those with less experience of the subject. Local works of lasting value will long

remain a souvenir of the activities of the British Armies in the Near East. As the methods are equally applicable elsewhere, the contained information should be of particular value to agriculturists, colonists, explorers, and pioneers in new countries.

The Author will never forget the sympathetic assistance rendered by all the Army Services with whom it was his privilege to work during the Great War. None of the hardships endured at Gallipoli and elsewhere can efface the pleasure recalled by remembrance of the happy relations that existed with all members of the Royal Engineer forces at the Front.

Thanks are due to Mr. James Romanes, M.A., F.G.S., for critically reading the proofs ; to my father, Mr. Beeby Thompson, F.C.S., F.G.S., for preparing the data dealing with water analyses ; and to the publishers, who have taken pains to produce so creditable a volume.

A. BEEBY THOMPSON.

18, St. Swithin's Lane.

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CHAPTER I

PRINCIPLES OF HYDROLOGY

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Introduction.—Modern views on sanitation have exacted such a change of policy in the selection, distribution, and treatment of water that these alone impose severe restrictions upon present-day war-time water supplies; but quite apart from such developments the enormous size of modern armies demands methods very different from those employed in the movement of smaller bodies of men. Lengthy occupation of restricted areas by considerable numbers of troops and transport animals causes all surface supplies of water to become badly fouled, whilst armies in retreat do not hesitate to render water supplies unserviceable by methodical destruction of works or intentional fouling of wells. In temperate climates, the water supply to an ordinary field division with its artillery and transport represents considerable quantities, but in tropical and sub-tropical countries much greater demands are made for water by troops burdened with heavy equipment and accompanied by excessively worked animals. The medical departments are especially insistent upon liberal supplies of water in field hospitals and clearing stations; and prolonged trench life develops conditions that can only be rendered supportable by moderate supplies of good water.

There can be no doubt about the value of good water to

men and animals in times of stress. Time after time on active service attention has been specially called to the great and immediate improvement in the condition of animals that have been watered from well waters after a period of watering from fouled or muddy streams often infested by leeches which abound in some areas. Accepting the urgent need of providing modern armies in the field with abundant supplies of good water as an axiom, there comes next the problem of how to furnish such quantities in the shortest possible time. Obviously the slow methods usually employed in the construction of works for the supply of towns and cities, often of no greater population than bodies of encamped troops, are inapplicable to warfare conditions, and means have to be devised for quickly determining when and how water should be obtained, and the quickest methods of distribution with the appliances at the disposal of the armies.

In Western Europe where geological surveys have been made in most countries the general distribution of underground waters is known, and the water problem resolves itself into the supply and use of appliances and machinery best adapted to develop local resources quickly. This subject is dealt with elsewhere. When, however, little or nothing is known of the geology or hydrography of a country a practical knowledge of field structural geology is invaluable, and its intelligent application may save weeks of waste work and much physical discomfort to troops, and perhaps even the health and striking power of an expeditionary force. Gallipoli especially emphasised this feature, where three army corps were compelled for months to confine their operations to three small and isolated occupied areas enfiladed by enemy artillery and relying mainly upon the perilous expedient of importation of water from Egypt, under the erroneous impression that useful supplies of potable water were non-existent. There were times, during storms, when for days the discharge of water from tank ships was impossible, and available reserves were reduced to practically nil, even after exercising economies which imposed severe hardships on the men. At no time was fresh water available at Anzac and Suvla for any other purpose than that of drinking. The

sea proved a poor but unavoidable substitute for all other purposes.

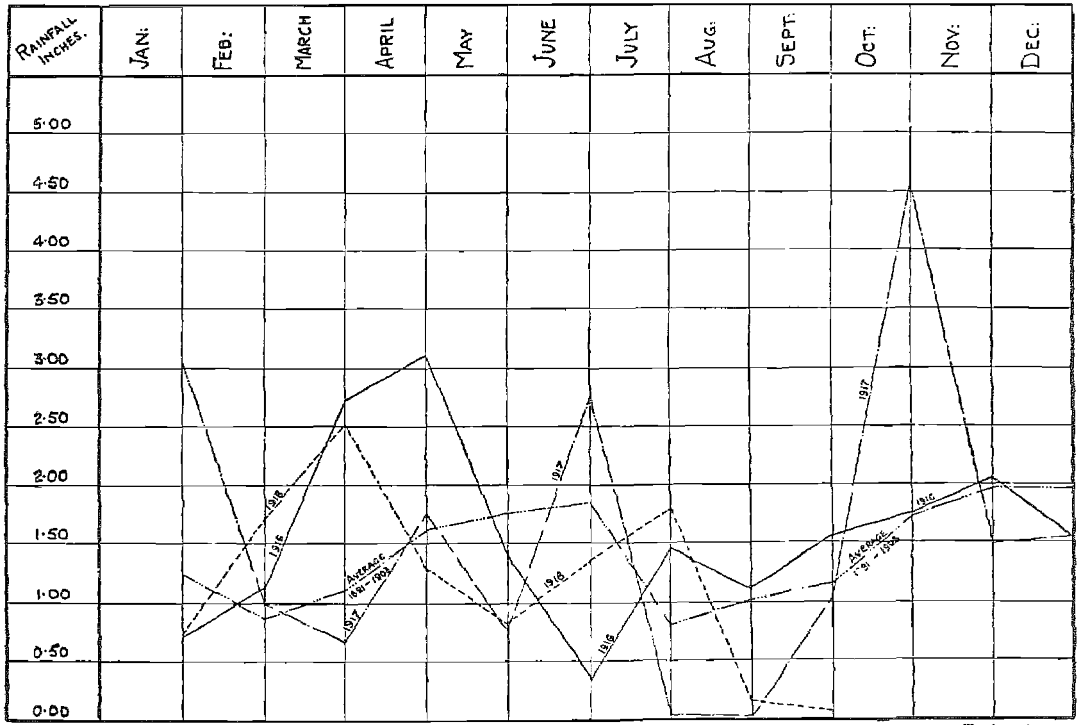
Divining.—It would be well here to refer to the fallacious ideas concerning "divining," as there appears a very general faith in "Diviners" or "Dowsers" who, armed with a hazel twig or piece of wire, indicate the occurrence of water. That some people of a nervous temperament are influenced by an unknown force or have a peculiar instinct usually attributed to water in motion cannot be denied, but the practical application of this gift is usually most disappointing. True "diviners" generally realise their imperfections by successive failures, but the less scrupulous are frequently led to apply elementary scientific knowledge or seek geological information which naturally only serves to confuse and nullify the value of any occult powers they may possess. The public hears much of successful divining but little about the innumerable and costly failures that are more usual; consequently, the ignorant are disposed to attribute to the "dowser" much greater importance than his attainments warrant. The writer has frequently watched "dowsers" at work, and has had opportunities of testing their prognostications. Usually they are cautious in their predictions about depth and quantity, and if these two factors are ignored there are few places in Europe where water would not be found at some depth. The honest "dowser" appears able only to locate surface waters or those, say, within a depth of 50 ft., but even he usually fixes on one point rather than a succession of spots or a belt; but so many failures result that even if he practises his gift conscientiously there must be other substances than water which equally excite his nervous system.

A feature that is difficult to explain is the inconsistency of two "dowsers" locating different points, each undiscovered by the other; likewise it is difficult to explain the reason for fixing a point in a region where water in equal quantities and at an equal depth would be found anywhere for miles around; in fact, in such circumstances the powers of the "diviner" would only be established by his discovery of a place where water was non-existent. There are occasions when "dowsers" can do no harm, and if there is anything in the art value should result. These occasions are when

water occurs in sporadic pockets of gravel or sand amidst clays, or when it fills fissures or zones of decomposed rock not visible on the surface. In the absence of any definite scientific reason for locating a well at a particular spot the "dowser" could be given his chance, and to the author's knowledge the location of small supplies has resulted on several occasions. *Bonâ fide* "diviners" are certainly influenced by radium emanations, and they are usually of a neurotic temperament, and often unhealthy in appearance.

The exaggerated claims of exponents of divining should be accepted with considerable reserve, and the same applies to the vendors of mechanical devices that will disclose to the owner the presence of water, oil, and precious metals. It seems superfluous to ask why the inventors of such appliances should waste time in efforts to sell their wares when they could quickly acquire fabulous wealth if they were able to substantiate or put into practice a mere fraction of the claims they make. Careful investigations undertaken by reputable scientists in England and America have led to the unqualified condemnation of "divining" as a useful art.

Origin of Water.—Fresh water is mainly derived from condensation and precipitation of aqueous vapour carried by winds to spots where the atmospheric conditions no longer allow the atmosphere to retain its contained moisture as a vapour or in suspension. All precipitated water doubtless owes its primary origin to the sea, which was a primitive product of obscure chemical reactions associated with the birth of the earth's crust. Water may fall as rain, snow, sleet, or hail, in gentle showers or deluges; but dews, fogs, and hoar frosts may make important contributions under certain conditions. Potable waters are almost exclusively of so-called meteoric origin, thus distinguishing them from indigenous, primary, or connate waters, as the original waters of sedimentation are variously designated. These latter waters are generally deep-seated, and have escaped the influence of meteoric waters that usually circulate in porous sediments of moderate depth. Indigenous waters are usually saline, as in most cases the containing beds were deposited in sea water, and they also contain other salts



[To face p. 5.

PLATE I.—RAINFALL AT SALONIKA, 1916–17–18, AND AVERAGE BETWEEN 1891 AND 1908.

derived by solution from the beds with which they have so long been in contact.

Rainfall is measured by a rain gauge conveniently located to avoid interference from draughts, trees, buildings, etc., and from figures so obtained a measurement of precipitated water over an area can be calculated. The amount varies from practically nil, or a few inches only, to several hundred inches in a year, a common figure for temperate climates of medium elevation being 25 to 30 in. a year. In the Salonika area an annual rainfall of 18 in. was about the average.

Great errors in calculations of water precipitation may arise from casual rain gauge measurements. As a rule the correct rainfall of a district can only be obtained by employing a large number of widely-distributed gauges owing to the influence of storms and topography. It is well known that in the hills the rainfall is higher than in the plains, and that where there are prevailing rain winds the fall on the leeward side greatly exceeds that on the windward.

Rainfall usually increases with altitude, and in most hilly districts the showers may be observed clinging to and following the higher ranges. In many tropical countries the clouds may be seen forming towards midday above the higher ground where the ascending moist warm air becomes chilled below the point at which it can hold its content of moisture. At midday the clouds may sometimes be seen gradually re-evaporating through solar heat. One of the most wonderful sights in the world is to witness at sunrise the ascent of massive white clouds which entirely fill the valleys and plains below the Himalayas. At an altitude of 5,000 to 8,000 ft. in a clear still atmosphere and with a cloudless vision of 20,000 to 29,000 ft. snow-capped peaks the sun is brilliantly reflected from the upper surface of the restless billows of clouds below. Within an hour or two these clouds have passed a sightseer obscuring for a time his vision and can then be seen gradually creeping up the mountain flanks to the snows following closely the ravines and depressions where air currents are induced.

An inch of rainfall is equivalent to about 22,600 gallons (say 100 tons) per acre, or 14,000,000 gallons per square mile.

Occasionally beds are fed by Magmatic or Juvenile waters derived from chemical activity at great depth ; or ordinary sources may be supplemented by vadose waters, the condensation of aqueous vapours connected with vulcanism.

Quite considerable quantities of water may be derived from dew or condensation of gaseous water. Large surfaces of the waterless rock of Gibraltar are faced with galvanised iron sheeting, against which warm moisture-laden air strikes and is chilled with condensation and precipitation of water that is conducted to tanks. The iron surfaces much more quickly radiate heat than the earth below. Where considerable diurnal variations of temperature are registered, as on mountain peaks, the reduced night temperature causes considerable quantities of water-saturated air to be drawn into the pores of rocks, in which the water globules coalesce and sink into the strata below the influence of temperature variations. Even the admission of gaseous water may be the cause of introducing much moisture, but in the latter case the liberation of latent heat raises some difficulties. Such temperature variations promote the creation of ice caves in some cold countries, where a small surface aperture permits cold air to descend and replace the relatively lighter warm air, causing moisture to be first precipitated and then frozen on the sides of the cave.

Changes of temperature and variations in barometric pressure and humidity not only cause great precipitation of water under certain atmospheric conditions, but the two former being coincident with rainfall operate in sucking moisture into the ground at times, and so assist the process of absorption. In sheltered positions on mountain peaks important supplies of pure water may be formed in this way, which either collect in rocky depressions or may be admitted into porous rocks from which it emerges lower down the mountain sides as springs. The breathing of rocks, that is, the alternate inhaling and expulsion of gas with variations of atmospheric pressure is often strikingly manifested in wells and underground workings.

Economics of Sub-soil Waters.—Ground water may be considered to comprise all liquid water that occurs in the cavities and pores of the earth's crust to a depth of

about 3,000 ft. Rainfall is disposed of by the following means :—

(*a*) Infiltration or absorption by the earth.
(*b*) Run-off to sea.
(*c*) Consumption by plant life, etc.
(*d*) Evaporation.

The meeting of cold northern winds with hot, moisture-laden southerly breezes causes at sea those dense fogs or heavy dews that saturate the decks and clothing. Fogs and precipitations of moisture without fog are encouraged by the presence of finely-divided particles in the air, thus accounting for the frequency or accentuations of fog around towns. So great is the fall of dew nightly in some tropical climates that expeditions have often to await the advent of the sun before tents and goods can be packed up.

(*a*) Infiltration or absorption varies greatly according to the nature of the beds at the surface. Whilst a porous, coarse sand or gravel may absorb the whole rainfall of a region, a damp clay or a crystalline rock may admit nothing. Some surfaces which have been well baked by the sun may repel water for a time before becoming sufficiently wetted to ensure its admission. Certain thick loess (cotton soil) deposits have the property of absorbing the whole of a season's rainfall, which later may be again abstracted by capillarity and evaporation during a subsequent dry season. As the content is mainly confined to capillary pores no economically useful supplies of water are obtainable. The alternate contraction and expansion with seasonal changes is the cause of much disturbance of buildings erected on such ground.

Some cavernous limestones not only receive the whole of the rainfall of a district, but will lead away into the bowels of the earth the whole flow of a large river when it reaches the limestone outcrop.

(*b*) Run-off. The ratio of run-off to absorption is very variable and is dependent upon :

(1) Geological nature of the ground.
(2) Topographical features.
(3) Nature of precipitation.
(4) Atmospheric and climatic conditions.
(5) Character of vegetation.

(1) The run-off varies according to the nature of the surface soil and of the geological strata. Porous limestones or uncemented sands may absorb the whole rainfall as golfers on sandy courses well know, whilst stiff, damp clays or hard crystalline or metamorphic rocks may absorb practically nothing. Between these extremes all intermediate stages occur. On flat-lying areas the sub-soil level of saturation may rise to the surface even in sandy zones, in which case the country becomes flooded until the water-table is depressed again by sub-soil drainage or evaporation.

After long periods of drought some clays will readily absorb the whole product of a rainfall not lost by evaporation and plant absorption, but Nature often interposes compensations by causing the dry clays to crack and expose fissures which admit water to underlying regions before absorption and expansion by the clays can seal the passages. On certain soils and some clays these fissures due to drying of the beds may reach a depth of many feet and be wide enough to render movements of men and animals unsafe.

(2) Topography plays a very important part in determining the ratio of absorption to run-off in hilly districts. Steeply inclined land facilitates the rapid movement of water over the surface and, consequently, diminishes the opportunities for absorption. Likewise areas much cut up by drainage channels cause the rapid removal of water, and the relationship of their direction of flow to the strike of the beds influences absorption. Wet lands are often artificially canalised for drainage.

(3) An important influence on proportional loss by run-off is the character of the precipitation of the water. Slowly melting snow or ice is one of the great balancing factors of nature. Many countries owe their perennial streams largely to the gradual melting of winter-deposited snow by summer heat, and even on low-lying ground where snow never

lies for long, its slow melting is a great aid to absorption. In cold countries frost may render the earth impermeable long after the surface evidence of frost has disappeared.

Heavy storms are less valuable as feeders of subsoil water supplies than steady and prolonged rains; indeed, heavy thunderstorms may hardly moisten the earth a few inches beneath the surface, especially if the topography is such as to facilitate rapid drainage.

(4) Atmospheric and climatic conditions are of immense importance in influencing absorption, and consequently run-off. Water precipitated as light showers followed by sunshine and wind may be all returned to the atmosphere by evaporation, even if the total rainfall in the aggregate reaches high figures. Much depends upon the saturation of the air, a property which may be measured by the difference between the dry and wet bulb thermometers. Air may be so charged with moisture as to be incapable of absorbing more moisture, or it may be so dry that all moisture is quickly taken up.

In arid countries like Egypt and the Sudan, at certain seasons even such a deliquescent substance as calcium chloride crumbles away into a dry powder on exposure to the air. Half an inch may evaporate daily from a sheet of water; indeed, so great is the evaporation that the storage of water entails losses that materially modify the value of impounding schemes. In Upper Egypt the evaporation reaches 5 ft. per annum from an exposed water surface. Still higher evaporation has been reported from Central Australia where as much as 100 in. per annum has been named.

The total evaporation loss of a drainage system is the difference between the rainfall and the flow of water to the sea, modified, however, by the consumption, retention, or re-evaporation of water by plants and animals. Losses by evaporation are not

confined to water surfaces, for where unprotected by vegetation capillary water is constantly rising to replace that evaporated on the surface, and in some countries where the water-table is within range of the force of capillarity its prolonged action, coupled with evaporation, leads to the deposition of efflorescences of salts of lime, potash and soda. which may acquire commercial importance.

Ploughed land, whilst beneficial in assisting the entry of rain water, may be a source of excessive loss when the showers are intermittent and evaporation is given free play.

(5) Vegetation consumes very considerable volumes of water, and is itself both a source of loss and gain, according to circumstances. By assisting in the formation and retention of a soil the run-off to drainage systems is retarded, and an absorbent sponge is produced; but light showers may be entirely evaporated from the leaves of deciduous trees, whilst in the case of conifers scarcely any water clings to the foliage. Grass land tends to aid in the preservation of water, although light showers may be largely evaporated under some meteorological conditions.

Only a comparatively small proportion of the water which falls on the earth descends to underlying strata such as constitute reservoirs for deep-seated supplies. In its descent through the surface layer of soil vegetation exacts its requirements; and capillarity ensures prolonged moistness, by replacing that lost by evaporation, and it is only where the soils are very porous that moderate quantities sink out of reach of surface influences. When not underlain by impervious clays or rocks water would descend vertically through a region of aeration to a zone of saturation whose level would be governed by the facilities for its escape, either artificial or natural, through the medium of springs. Where non-porous sub-soil conditions existed surplus water would be forced to flow over the surface until it reached channels which greatly diminish the opportunities of charging ground water supplies.

With so many variables it is obviously impossible to do more than arrive at an approximate estimate of the percentage of rainfall that reaches ground water supplies in different countries. In England, where there is a great variety of topography and geology, from 20 to 25 per cent. of the rainfall is considered to percolate into the ground and feed ground water supplies, and of the remainder about two-thirds are lost by evaporation and absorption by plants, and one-third constitutes surface run-off. With a 30-in. rainfall the results under temperate conditions resembling England with its variety of surface relief and geological features, the distribution would be approximately :

Evaporation and absorption by vegetation . . .	50 per cent.	15·0 in.
Surface run-off . . .	25 ,,	7·5 ,,
Percolation. . . .	25 ,,	7·5 ,,

On the Severn basin, draining some 1,250,000 acres (195 sq. miles), the evaporation and absorption losses have been estimated at 66 per cent. with a dry season rainfall of 18 in., and 49 per cent. with a 21-in. rainfall in the wet season. In the Thames basin to Teddington, covering about 2,350,000 acres (370 sq. miles), the losses have been estimated at 79 per cent. with a dry season rainfall of 17 in., and 65 per cent. with a wet season fall of 19 in. The evaporation and absorption losses on high moorland and pasturage underlain by crystalline or metamorphic rocks have been given as 16 to 19 per cent. with a 80-in. rainfall, and 22 to 25 per cent. with a 60-in. rainfall.

Sedimentary strata, to which ground waters of economic importance are mainly confined, are usually inflected and inclined so that the exposed edges of successive strata outcrop at the surface beneath a layer of disintegration or soil that supports any existing flora. Along outcropping beds of porous rocks water readily descends until that deposit is saturated to some line of overflow. This process is the cause of intermittently flowing streams and springs that represent the overflow of surcharged beds resulting from seasonal rainfalls. With porous strata horizontal and unbroken for indefinite distances and overlain by impervious

deposits, no extraneous water would gain admission, and all precipitated water would constitute run-off to the sea or be lost by other means. Fortunately for humanity, hill ranges, where rainfall is highest, present the upturned and disturbed edges of strata under circumstances that facilitate absorption; and rivers carve out channels in sediments receptive for water. How much water can replenish ground water supplies depends upon a variety of circumstances. Rivers like the Nile are known to lose large volumes of water at certain reaches, and wherever rivers cross or follow unprotected porous strata water is bound to enter if the beds are unsaturated. Those rivers carrying a sandy detritus are naturally better feeders of sediments over which they travel than clay or silt-carrying streams which might form an insulated bed.

Except where compelled to force an outlet to the sea across ranges of hills, rivers usually follow the main tectonic features of the country, and in this way the maximum of length of strata is exposed to their influence; that is, the majority of rivers follow the strike of the beds and not the dip. The other impediment imposed by Nature on rivers is their sinuosity, which so impedes the progress of flood water to the sea that absorption is assisted.

When it is wished to draw large volumes of water from an area of restricted catchment either by pumping or through artesian flows it is desirable that some approximate estimate of the available water for renewal should be made. In impounding schemes the quantity is closely calculated from average rainfall figures corrected for evaporation and absorption. The amount of water discharged from a large drainage area in England with a rainfall in the neighbourhood of 30 in. a year has fallen as low as 70,000 gallons per day per square mile, but this quantity may often reach 2,000,000 gallons per square mile per diem, and for brief intervals this latter figure may be doubled. Converted into inches of rainfall the minimum corresponds to a rate of $\frac{1}{200}$ of an inch daily, or 1·82 in. per annum, which often rises to near $\frac{1}{7}$ in., or a rate of 52·5 in. a year.

As sources of water supply strata must not be retainers merely capable of holding water but must have the property

of transmission ; consequently, those beds in which the pore spaces are very fine are not necessarily of use as suppliers of water. Water-holding strata may be classified as under :—

(1) Those which beyond a small trace of " quarry water " are incapable of holding water except in fissures or along decomposed zones. These comprise igneous and metamorphic rocks, such as granite and other crystalline rocks, quartzites, gneisses, schists, slate, etc.

(2) Beds that will absorb but not transmit, such as plastic clay, fine sandy-clays, and marls.

(3) Fine-grained rocks which allow slow passage of water, as chalk, loess, limestones, and dolomite.

(4) Clastic rocks with uncemented grains of sufficient size to allow the free passage of water within the pores. The critical size of grain is from 0·1 to 0·2 mm. diameter, above which passage is easy, and below which movement is slow or negligible.

(5) Gravels, shingle, and boulder beds in which water can freely circulate.

The approximate porosity by volume of various kinds of sediments is as under. Their relative powers of transmitting water are in the reverse order to their porosities :

Clay or marl . .	50 per cent.
Chalk . . .	45 ,,
Fine sand . . .	42 ,,
Medium sand . .	40 ,,
Coarse sand . .	36 ,,
Fine gravels . .	34 ,,
Coarse gravel . .	32 ,,

Wide fluctuations in porosity arise from mixtures of fine and coarse sands ; in fact, rarely does a sand of a particular grade extend far. Only the last three types yield up their water contents freely, but from most of the others water will gradually seep if an excavation is sunk below the line of saturation. It is interesting to recall that many fine-grained rocks owe their impermeability to the presence of capillary water.

In some limestones, dolomites, chalk deposits, and even igneous rocks large volumes of water may be drawn from

fissured systems or solution channels, but their penetration at depth is often a matter of chance. Occasionally important supplies of water are obtained from decomposed igneous or gneissic rocks. Joint cracks and bedding planes in compact sedimentary rocks are often a prolific source of water. It is claimed that chalk supplies are entirely obtained from the intricate network of fissures that prevail or from the interposed flint bands.

The freedom with which sands yield up water varies as the square of the effective diameter of the grains,[1] and the rate of movement in fine sediments is influenced by temperature which reduces the viscosity and surface tension of water. The nature of the mineral constituents of sands bears on the subject, but these refinements have little practical bearing on water supply problems as applied to military exigencies or economic problems.

A common practice is to fire a heavy charge of high explosive in bore-holes failing to give a yield in strata where water is known to exist only in a fissure system. In shafts a small influx will be followed by headings or adits until larger feeders are struck.

Intensive pumping may lead to the abstraction of ground water at a greater rate than percolation can replace. This is happening in the Thames basin to-day where, since 1820, the level of water below London has fallen at a rate of between 1 and 2 ft. per annum. It is said that about 200,000,000 gallons per day are pumped from the London basin. The Kharga Oasis of Egypt was so actively developed with wells that the yield has greatly diminished. Beadnell estimates the total artesian flow at 12,000,000 gallons a day: many wells yielding 25,000 gallons per hour.

Underground movements of water are very slow compared with surface flows; whereas a river may flow at a velocity of 3 miles per hour the underground flow in gravels may not exceed the same rate per annum although the gradient is the same. For this reason it is inadvisable to draw on supplies near the sea at a rate exceeding the capacity of the gravels or sands to transmit water, otherwise salt water is

[1] The effective size of the grain is that size of screen which will pass 10 per cent. of the particles.

drawn in. The friction imposed on underground movements of water is well illustrated by the lag of rise of the water-table after rainfall; many months often elapsing before the influence of a season's rainfall is felt in wells and springs.

In one interesting case investigated by the author, a large mountain-encircled, gravel-filled valley was drained by a single outlet channel less than 1,500 ft. wide, communicating with the sea, and at sea-level artesian wells flowing 50,000 to 200,000 gallons per day were struck with a static head of about 6 ft. above sea-level. As it was desired to draw from wells fed by the valley to the extent of about 650,000,000 gallons a year it was essential to know whether this could be safely anticipated. Calculations showed that with a 60-in. minimum annual rainfall fairly evenly spread over eight months with perhaps no month devoid of some precipitation, the amount required represented less than 4 in. of rain, and less than $6\frac{1}{2}$ per cent. of the total minimum volume falling on the drainage system. There appeared consequently no reason to doubt the capacity of the area to supply demands if the rate of artificial abstraction was kept within the capacity of the gravels to maintain the supply; otherwise salt water might be drawn in.

Wells near the sea frequently flow and ebb with the tide, showing how the sea influences the water-table. Such wells are always liable to contamination with salt water if the water-table is too much depressed. In the same way the flows of certain sensitive artesian wells are affected by differences of atmospheric pressure. Curious noises are caused in some dug wells by indrawn or expelled air or water during barometric changes.

Water-table.—Water entering porous rocks first coats the particles with a film, then displaces the contained air and sinks until it reaches a zone of complete saturation, above which only a layer kept moist by capillarity may exist. This level of saturation is known as the water-table, and it bears some rough relationship to the surface relief and to the drainage system of the area. It naturally lies at a fluctuating depth, depending upon seasonal rains and the nature of the beds into which the water finds admission.

Beneath the water-table any open-pored stratum is

likely to yield copious supplies of water, except where such occur as isolated lenticles confined within masses of clay or other fine-grained beds. Those waters which rise above the level of saturation on being struck are known as artesian, the head being caused by an overlying impervious layer which holds down water admitted where an uninterrupted porous bed reaches the surface at some more elevated and, perhaps, distant point.

Under certain conditions a false water-table may exist, due to the occurrence of an impervious stratum above a zone of aeration. In consequence, water will flow from an upper into a lower stratum if the two beds are pierced by a single well or bore-hole.

At other times an irregular water-table may be caused by the obstruction of a fault which breaks the continuity of sand and imposes a barrier of impervious beds. Artesian flows may be occasioned under such circumstances, as also where sand lenticles tail off into mere stringers or disappear down the dip of an inclined series of sediments.

Artesian flows may likewise be formed by the difference of density between sea and fresh water. Thus, in deltas, deep-seated waters will have an artesian head that corresponds to the difference in weight of an equivalent column of salt and fresh water. A well 1,000 ft. deep sunk at sea-level might have an artesian head of 15 ft. due to differences of density.

Sometimes the absorption of water is so rapid on porous strata during prolonged spells of rainy weather that the water-table rises sufficiently to cause important flows of water along low-lying water-courses that customarily carry off only surface drainage. These intermittent springs, separated by perhaps many years of repose, often cause alarm and mystify local inhabitants, and at times much damage may be done to cultivation and dwellings arranged in ignorance of this eventuality. These *Bournes*, as they are called, are prevalent in chalk areas, and that of Croydon has been known to cause an unexpected flow of over 2,000,000 gallons a day. These flows can be predicted by observations of the rising water-table in wells.

Only in exceptional cases does the water-table lie below

sea-level to which normally all meteoric waters tend to descend, so that within short distances of the ocean the water-table can be approximately predicted by levels. So great is the frictional resistance of some sands that fresh water is often obtained well above sea-level from the dunes that fringe a coast line. Even on inhabited sandbanks off the Dutch coast copious supplies of fresh water occupy a central cup-shaped area, and resist the entry of sea water beyond a region of diffusion where brackish water is found.

The highest elevation of the water-table corresponding to a topographical "divide" is known as the "water-ridge." From this point the water-table descends to main drainage channels and to the sea. In the case of the Dead Sea, 1,200 ft. below sea-level, and the Caspian, 86 ft. below sea-level, all drainage on that side of the surrounding "divides" sinks to the level of these seas; and in Egypt there are desert oases with water-tables little above that of the Mediterranean.

Where flowing water mainly derived from distant sources passes a region of small rainfall, as the Nile and Euphrates, a reverse water-table is in evidence. Whereas in most river valleys the water-table rises from the banks landwards, in the case of the Nile the water-table falls from the river; the river taking the place of rainfall as a supplier of sub-soil water. In many large river valleys the water-table is directly influenced by the rise and fall of the river; a sub-soil wave following the variations in the river-level if sufficiently sustained to affect all the river sediments. A similar wave may be transmitted to water in the older rocks composing the ancient channel if they are suitable. A brief heavy storm may lead to a big surface flow without causing any material rise in sub-soil water. Usually the sub-soil wave continues to rise for some time after the flood has commenced to fall, and continues to fall long after the river has reached its minimum. The water so absorbed during flood and returned to the drainage in the dry season is a valuable contribution to the water supplies of a country, and a balancing factor of no little importance in regions of small rainfall relying upon distant rainfall. Sub-soil water-table (piezometric) contours are an interesting study, and are often a valuable

guide to the determination of underground geological features. Locally depressed or elevated water-levels indicate the presence of more porous and less porous strata, underground barriers, subsidiary supplementary channels, and other features that are a material aid in the selection of well sites.

The seasonal fluctuations of water-tables is frequently very considerable, and their measurement facilitates the calculation of run-off and capillary losses. Many comprehensive studies on these lines have been made in the United States by officials of the Geological Survey, especially in the arid central continental regions where irrigation projects largely depend upon water saturating the enormous gravel deposits that fill the valleys and plains stretching from mountain ranges. This retention of moderately high water-tables in elevated plateaux throughout the dry season is mainly due to the obstructions introduced by contracted outlets and by lateral change of deposits into finer sediment that more slowly allows percolation to proceed. To the same latter cause is due the very frequent occurrence of high water-tables in the extensive inclined deposits of sandy sediments that stretch from hill ranges to the plains or coastal belts.

CHAPTER II

PRINCIPLES OF HYDROGRAPHY

Sources of potable water—Influence of hygienic measures—Hydrography of Macedonia.

Sources of Potable Water.—According to the meteorological, topographical and geological conditions are the methods of obtaining, conserving, and distributing water determined.

The following represent possible sources of supply for military field operations of moderate size :—

(1) Rivers, streams, and water-courses in flood (with or without filtration).

(2) Impounding reservoirs.

(3) Ponds, pools, and lakes.

(4) Rain, snow, and ice-tanks.

(5) Springs.

(6) Shafts.

(7) Bore-holes or tube wells.

(8) Evaporation of sea or other impure waters.

(9) Sundry expedients.

Naturally the extent to which any particular water supply is utilised depends upon local conditions, which are extremely variable. The advantages of, and objections to, the various services will be outlined in the following paragraphs :—

Rivers, Streams, and Water-courses.—Flowing surface waters are obviously subjected to many forms of pollution ; indeed, they are usually utilised as the convenient outlet for all offensive matter within a short distance of villages and habitations. Settlements were from time immemorial invariably located on the banks of rivers and streams and near natural issues of water on account of the advantages such water gave in providing supplies for industrial pursuits, if not actually for drinking, and for furnishing a convenient

outlet for sewerage and town drainage. Most river waters can be rendered innocuous by filtration and treatment, but these methods are rarely practicable or needful in field operations when the quantities required can, as a rule, be obtained from underground sources within valleys of fair magnitude. For watering animals, stream and river waters serve a very useful purpose, but when they have passed populous regions or camps they should never be used untreated for potable purposes.

Slow-running rivers meandering over muddy deltas or swampy valleys, even if removed from populated areas, yield objectionable and dangerous waters. The current is insufficient to wash away the fine detritus and decaying vegetable matter, with the consequence that objectionable slimy muds are formed in which thrive bacteria of all kinds. Although pathogenic germs may not be present, the conditions are such as promote and encourage their development if introduced, especially in warm climates ; consequently, such surface supplies should be avoided.

On the other hand, swift-running streams introduce conditions conducive to good water. Fine silt and macerated or finely-divided organic matter is swept away at once, the result being that sandy or gravel beds remain over which the water flows and splashes constantly exposing fresh surfaces and encouraging the absorption of oxygen from the atmosphere with the consequent oxidation of organic matter that may be present. Mountain streams are usually a very safe source if reasonable precautions are taken to protect them from village pollution or fouling by troops. They suffer, however, from the objection that during storms the water becomes turbulent, and is highly charged with suspended mineral detritus that for a while renders it unsuitable for any purpose. As a rule they quickly clear, and the water can be used again ; but if exclusive reliance is placed upon such streams for supplies means must be provided for storing sufficient water to carry over during such disturbed periods.

Rarely does military equipment include a great surplus of tankage, and in any case the storage of one or two days' supply for even a small unit would entail far more artificial storage than could be made conveniently available. A

plan sometimes adopted is to dam the stream, if not too wide, at some convenient point where a storage of several days' reserve water can always be accumulated. Above the intake a by-pass is excavated that will carry storm water to one side and discharge into the stream below the reservoir. This will enable the reservoir to be isolated by a sluice in the event of rain, and the water to be drawn from reserve till the stream clears again.

Mountain streams with perennial flows are usually fed by small springs issuing at numerous points and collectively aggregating quite a considerable quantity. Melting snows or surface drainage swell the streams in the winter months or rainy season, but during long periods of drought many mountain streams dry up entirely unless fed by springs, and even when so fed the quantities may diminish to valueless dimensions within a few months. The above arguments apply principally to mountain ranges of a few miles in width and two or three thousand feet high, or to the higher reaches of more massive blocks. Most mountain ranges are flanked or partially crossed by perennial streams that are confined to low-lying zones beyond the reach of anything but high-lift pumps and long-distance pipelines for camps at elevated positions. In malarial countries it is always in the hottest and driest season that the valleys are evacuated for the hills, thus complicating the problem of water supply. If water only were the consideration the reverse movement of troops would take place, namely, a descent to the plains from the hills.

Where streams decrease in volume to an extent that imperils requirements, the natural procedure is to impound in reservoirs and so collect the whole night flow instead of allowing its discharge to waste. Officers who note a marked decrease should always insist upon a daily measurement of the yield, which figures should be graphed. It will then be possible to forecast approximately when a certain stream will fall below requirements, unless supplemented by rains. Stream measurements must not be taken at casual moments or very unreliable data will result. Quite a considerable difference may be noted between the morning and evening flows in small streams, due mainly to evaporation during

the day-time; consequently, these measurements should be taken to secure a mean, one morning and one evening. The variations were indicated very clearly where the morning, evening, and mean yields of a stream in the Balkans fed by springs were plotted.

A curious phenomenon was witnessed in a Salonika river where an otherwise perennially-flowing stream ceased to flow entirely for several days after a heavy flood. This appeared to be best explained by the strong current having washed away a surface accumulation of clay which plastered the surface of the gravel bed of the river during normal slow flow.

Impounding Water.—Beyond the small schemes outlined in the previous paragraph, where stream waters are collected in their path by retaining walls at convenient spots, impounding schemes are outside the province of field military waterworks. They usually entail detailed surveys, accurate rainfall figures over a long period, and works of considerable magnitude occupying a long time and demanding much cement and masonry. In warm countries where malaria exists, the medical corps disfavours the accumulation of stagnant water in which the mosquito larvæ could develop. There is also the objection that unless water is fairly deep the growth of algæ is encouraged, weeds thrive, and the water becomes objectionable.

The small retaining walls required in streams are often quickly improvised by sandbags filled with earth being placed at some selected spot where a rocky or sound foundation can be reached, and where the contours assure a fair storage capacity. If these are neatly placed on a prepared base and carefully built up by cross-locking quite a substantial temporary wall can be made. A heavy flood might carry these away, but if a by-pass is arranged for storm water even this contingency may be avoided. When the retaining walls are not very large or high they may be made of masonry by building up with rubble and cement or even reinforced concrete, if sufficient cement is available. Usually the less ambitious scheme of sandbags or earth satisfies requirements.

Lakes, Ponds, and Pools.—Large lakes removed from habitations and on high ground usually contain good water;

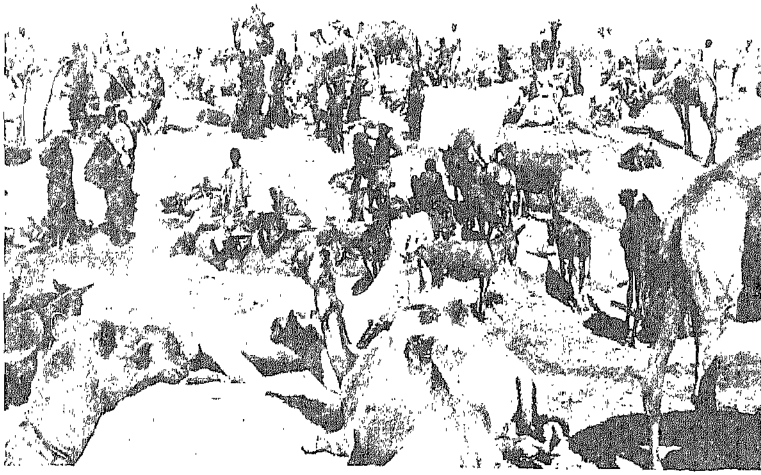


PLATE II.—SCENE AT KHORDOFAN (SUDAN) WATER HOLES.

Until bore-holes were sunk animals and men had to wait their turn till water seeped into the shafts (sunk into decomposed gneisses).

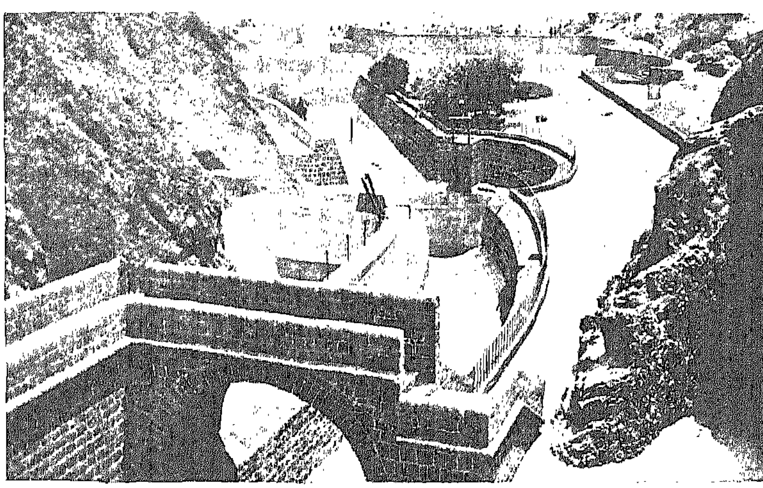


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PLATE III.—THE ADEN TANKS.

Ancient tanks discovered, cleaned out, and repaired by the British, and still in use. The watershed is the crater of an extinct volcano, and the whole region is a cinder heap.

those on low-lying plains are often nothing more than deeper parts of the swamps with which they are surrounded, and are very obnoxious and unsafe for water supplies. They also lie amidst unhealthy, marshy surroundings that are usually studiously avoided by troops. Lakes may be caused by a depression exceeding in depth the water-table of the district and so be constantly fed from below, or may lie in valleys whose outlet has been obstructed by geological phenomena, such as tectonic movements, land slides, or lava flows. Ponds or pools of stagnant water are equally unsuitable for potable purposes. Even for horse watering they should be avoided, as they are often infested with leeches which worry the animals. The so-called dew ponds on the South Downs of England are interesting, as representing small catchment areas for rain on the tops of the hills where heavy mists prevail and rain may fall when it does not elsewhere in the lower areas. Their impervious bed may be due to the constant access of cattle which puddle extraneous matter into clay-like mass. The interposition of a non-conducting medium diminishes losses due to earth heat. The lakes of Macedonia were only used during the Salonika campaign if other sources of supply failed.

Around the margin of lakes that derive their waters largely from crystalline rocks or sandy sediments considerable depths of porous sands may exist, and wells sunk into these yield valuable supplies of cool, clear water. Sometimes such waters are sulphurous through stagnation in sands containing decomposing organic matter, but this may be avoided at times by sinking near a main outflow or inflow where a fair underground movement exists.

Rain and Snow Tanks.—In regions where rain very sparingly descends and at long intervals, where potable water cannot be obtained by wells and no rivers cross the territory, recourse is had to tanks. In some countries all dwellings are provided with tanks into which runs the rain water from the roofs, and in other places public underground tanks have been constructed surrounded by a belt of reserved and cleared ground which acts as a catchment area for rain. Many Eastern cities rely upon such expedients for their water. Aden is still mainly dependent upon its rain-water

tanks at Crater on the hills above the city, and Jerusalem till recently mainly depended upon a tank system. In the provinces of Kordofan and Darfur, Sudan, the natives store water in the carved-out trunks of trees, called Tebeldi (Baobab tree), in the rainy season, and this is their sole source of supply in the dry months. Inhabitants of the hot, waterless plains of the Ural Provinces of Russia obtain their water from snow packed into underground chambers (ambars) during the snow-storms that prevail in the winter months. These storages furnish the only supply of potable water during the hot, rainless season. Expeditions into such waterless countries have been watered entirely by railway and animal transport in the intervals between successive oases, tanks, or wells.

Roof water is often polluted by the excreta of birds and the accumulations of dust collected during periods between rains. This danger may be reduced by attaching an arrangement that automatically rejects the first drainage of the roofs and only admits water to the tank after the first flush has passed.

The Germans and Turks made use of ancient, concealed Roman water-tanks in their march on the Suez Canal, but as a military expedient such methods are only of use to small punitive expeditions and reconnaissance parties. Modern drilling methods have now enabled supplies to be quickly obtained where formerly water was thought to be non-existent; but there are vast areas where only highly saline and non-potable waters can be obtained within the reasonable reach of the appliances of man. In nearly rainless parts of Arabia, rain water is collected in large underground caverns excavated in fairly non-absorbent limestones, and religious devotees desiring to acquire merit or perpetuate the name of a deceased relative construct tanks for the common welfare. Unfortunately no merit is acquired by their preservation, so they fall into disrepair and disuse like the Burmese pagodas.

Rain water is, of course, quite pure if the surroundings are adequately protected from contamination, but after long storage it becomes objectionable from the growth and decay of algæ. It is also difficult to protect the tanks

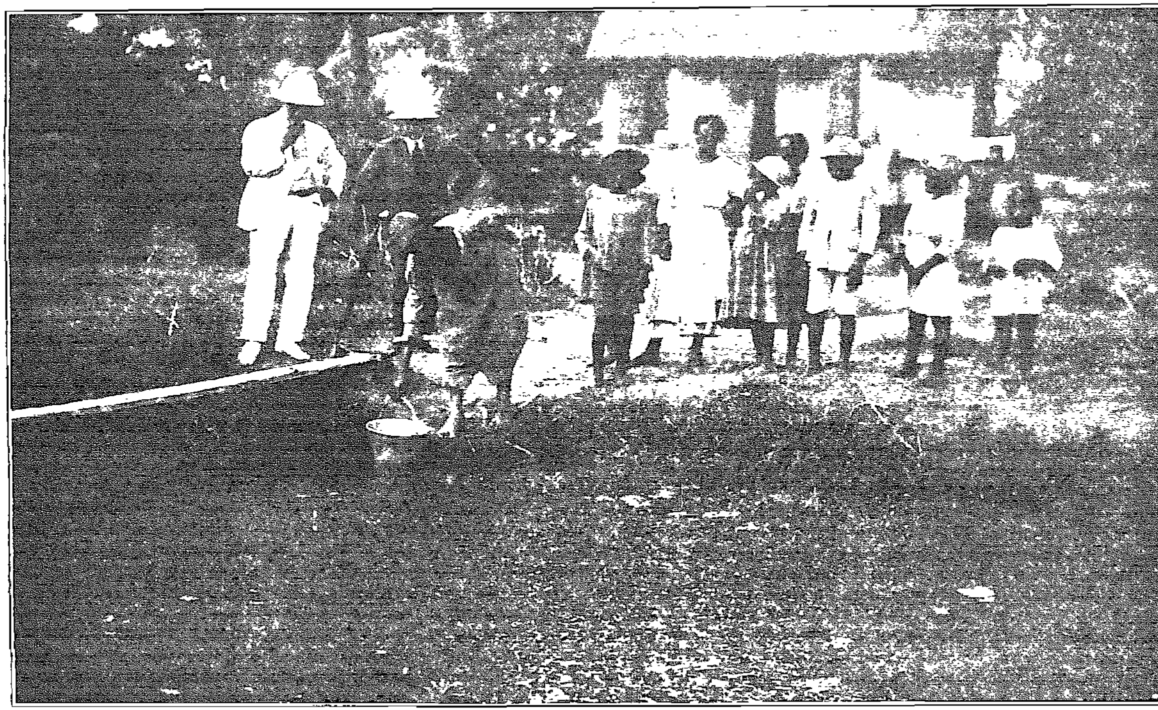

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PLATE IV.—NATIVE WATER SUPPLY IN BRITISH GUIANA (DEMERARA).

The negro population use these infested drainage canals, into which sewerage and refuse is led, for all domestic purposes in the absence of other available supplies.

from the entry of dust, and the admission of noxious forms of animal life which in their search for water get drowned and pollute the water. The unpleasant vegetable taste of long-stored rain water cannot be eliminated by boiling. Underground tanks are usually made of masonry or reinforced concrete, and are roofed over and screened for the exclusion of light, dust, and insect or animal life. Water should be withdrawn only by a pump, and not by the introduction of a vessel through a manhole. In many countries it is the custom to excavate large pools in depressed areas where the soil is moderately impervious and where a fair supply of water would accumulate during rains. Even fairly porous beds may be rendered impermeable by a lining of puddled clay which plugs the pores of the underlying beds. In dry countries where there are periodical if brief rain storms, such ponds may never become dried up, and always yield water, even though objectionable in quality.

The village ponds of Africa and India are used for drinking, washing, and bathing, and as watering places for cattle and animals whose habits are too familiar to need description; and as the water content is derived from the drainage of an area polluted by live stock and human beings provided with no sanitary arrangements, it is a marvel that so many inhabitants survive. The irrigation canals of British Guiana are used as sewers and sources of water supply with the natural result that the indigenous population is being decimated.

Springs.—By far the safest natural supplies of water are springs. Only in exceptional circumstances are spring waters subject to injurious contamination, but the effluents are frequently more or less mineralised as a result of underground movement of the water. The origin of springs is discussed more fully in p. 50, and it is only necessary to remark here that if properly dealt with at their source they need very rarely be objects of suspicion.

Springs occur in several forms—

(*a*) Seepages or sweatings.

(*b*) Outflows from one or more spots.

(*c*) Submarine flows.

The yield of springs is far less liable to variation than the

flow of streams, although the latter may be largely fed by springs, but waters that reach the surface are subject to a whole series of influences from which subterranean waters are immune, such as dissipation, absorption, evaporation, consumption by plant and animal life. Every effort should be made to tap and control springs at their source, and the works undertaken should be of such a kind that the introduction of foreign matter, insects, etc., is impossible. Often the most elementary precautions are neglected in protecting waters of initial bacteriological purity.

Caution should be observed in the hasty acceptance of springs, as time after time so-called springs of water have been traced to long distance aqueducts or fractured aqueducts connected with either remote or near-by sources. Wherever the Romans spread they executed important and praiseworthy water schemes which in many places are still in use, although often neglected and patched up; indeed, it is remarkable how little regard has been paid by their successors to services of such value and permanence.

From some noteworthy springs near Salonika aqueducts lead in all directions to fountain heads on the main roads and to the city itself. By an elaborate system of aqueducts around the mountain of Kotos at Hautiac as much as 400,000 gallons daily is collected and led to Salonika, but the sources have been shamefully neglected. Peasants have pierced the pipes and mains for supplies for their cattle. Masonry has been carelessly removed to lead off supplies to gardens, etc.; and the sources have been allowed to fall into disrepair to become polluted by cattle and fouled by human agencies. Fountain heads popularly attributed to springs should, therefore, be carefully examined before the water is passed as potable. Many of the earthenware pipes that convey the water to the fountains are led from the bottom of stream beds, often below a masonry barrage which holds up the water. If, therefore, the upper reaches of such streams are utilised by troops or pass habitations as is generally the case, it will be seen how dangerous such sources may become. Conditions such as those outlined were discovered in a number of cases during the Salonika campaign. The inhabitants themselves are practically always

PLATE V.—MACEDONIAN VILLAGE WATER SUPPLY.

Water is usually led from distant springs by underground masonry conduits. Disgracefully neglected works of great artistic merit adorn these fountain heads.

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PLATE VI.—ABANDONED RECORD OF ANCIENT CIVILISATION.

These fountain heads are typical of south-eastern Europe, but generally neglected. The source of the water is often distant and obscure, being led to the fountain by masonry conduits.

quite ignorant of the source of their supplies, and their ideas are often very absurd, and should never be accepted without independent confirmation.

Another danger that should be carefully guarded against is the re-issue of a true spring water after a long passage just beneath the surface of the ground. The outflow of a spring may descend to low ground, where it follows a course in porous beds near the surface before reappearing as a definite flow of water. Its underground progress is marked often by a strip of green vegetation that attracts animals for feed, thereby fouling the soil and polluting the water at each shower of rain. The loss and reappearance of water in stream beds is a common phenomenon which is attended as a rule with far less danger than such flows as those above described, as in the former case they are regarded as true springs and thus assumed to be quite safe. One such case—near Grand Couronne, by Lake Doiran—is especially recalled, as much difficulty was experienced in convincing officers that such was the case, although the original point of issue was clearly traced and the course of the water subsequently followed to its real source a mile away.

One naturally expects to find springs along water-courses which have carved out deep channels in the district they pass through. There is sometimes a difficulty when water appears and disappears at intervals along a stream course in deciding which are springs and which is really a reappearance of stream water. A useful clue is the temperature of the water. In warm weather the higher temperature of surface flows distinguishes the water from springs, and in cold weather the reverse may be observed. The erratic appearance of water along the bed of a stream is generally due to irregularities in the bed of the stream. Where there are thick deposits of coarse gravel through which water can freely travel the whole flow of a stream may pass unobserved beneath the surface, but when a ledge of rock or a bar of impervious material crosses the channel the water rises to the surface and continues so until a deeper deposit of porous material is reached. At times, however, some water is actually lost through entering into porous and unsaturated beds outcropping below the gravel, and when the flow is

small during dry seasons the whole of a supply may thus be lost. On the other hand, in a succession of unconsolidated sedimentary deposits other beds may yield water and cause the formation of a spring where the gorge or channel has descended to their level.

Although seepage springs are by far the most common in Nature they are rarely the most important. It is, however, surprising what large volumes of water can be collected by the intelligent canalisation of seepages. To those unacquainted with field operations it is worth recording that the presence of a spring is usually denoted by a rank growth of water-loving reeds or plants. Strips of green foliage amidst dried-up surroundings immediately attract the attention of a keen observer. A mossy or fern-cloaked escarpment amidst dissimilar surroundings proves the existence of a seepage stratum. Assisted by these clues the application of simple structural geology will enable one to trace the source and prospects of water. Amidst desert surroundings the appearance of certain shrubs or plants, and even a difference in the freshness of the foliage, will disclose to the experienced the presence of sub-soil waters of which there is no direct evidence. Some plants have the property of drawing water from a depth of 50 ft., and in the tropics the roots of forest giants may often be seen clinging to the precipitous sides of stream beds for a distance of a hundred feet or more to reach water. It is no uncommon occurrence for a seepage spring displaying no surface flow of water to yield 1,000 to 2,000 gallons per hour on the removal of the soil and the tracing of the main issues.

Limestone springs usually issue from a limited number of definite points, and are thus more easily located, as the water mainly follows solution channels. They may likewise occur at any elevation, and thus differ from the common seepage springs where water usually exudes along a strip of out-cropping rock overlying some impervious bed and contouring the hills. Some limestone (often dolomitic) springs are intermittent in action, such as the famous spring at the pool of Siloam at Jerusalem, referred to in the Bible as the disappearing waters. Here there is a natural syphon in the rock which leads to the expulsion of the contents of a

concealed cavern when the water-level reaches a certain level. Some hours are then necessary for the water-level to rise sufficiently to induce another flow. Other springs are artesian in character, due to the orifice of escape being sufficiently restricted and resistant to retain the water in the acquifer under pressure. A common form of spring also arises from a fissure in a rock not itself water-bearing though water-carrying. Such springs are erratically distributed and the source of the water is often very obscure, although they may give very important, consistent or persistent yields.

Some dolomitic limestones are cavernous in character, and enormous volumes of water find access to and traverse their midst. Into those of Mexico, rivers are known to disappear on the flanks of the Sierra Nevada, and wells sunk near the coast into the corresponding beds yield millions of gallons daily under a pressure of some hundreds of pounds per square inch. Below the Barbados coral limestones, which are underlain by tertiary clays, streams of considerable size flow gradually coastwards, and at intervals appear as springs on the beach or in the sea. In the Canary Islands important streams of water follow the course of porous lavas below harder varieties, and these are sought for by driving adits into the mountain side. In Florida some of the great limestone springs are credited with flows of 300,000 gallons per minute.

A fact which attracted general comment and questions during the War was the comparative permanence of springs high up on mountain ranges after long periods of drought when those lower down commenced to fail. The explanation is probably due to a number of circumstances acting separately or collectively. Firstly, water movements are essentially superficial, and it is unlikely that the circulation reaches far into the mountain mass; secondly, the lower springs are probably largely fed or supplemented by those above through re-percolation after issue; thirdly, the evaporation and absorption losses diminish greatly with elevation due to reduced temperature, prolonged mists, and prevalence of clouds; fourthly, there may be rain or heavy dews to supplement higher springs; fifthly, there are

often near the top of mountains plateaux which more gradually feed the springs and present a larger and less inclined area to receive deposited water.

Subaqueous springs are probably as common as subaerial, but are naturally only visible under particular conditions. They may often be detected in lakes, and in one case at Lake Doiran the writer drove a tube well into such a spring and found there was a fair artesian head, the level being several feet above that of the lake. Some enormous submarine springs were located in the Gulf of Corinth near Delphi during the Salonika campaign. So large was the concentrated volume of water that for a radius of many feet this sea was in a state of ebullition, and the water could be drawn without contamination by sea water. On the northern side of the range such large flows issued from the limestones that the water was used for irrigation of cotton lands. Delphi itself probably owes its existence to the wonderful spring of water issuing from a crevice in the limestone within a few yards of the classical oracle.

The temperature of spring water is often commented upon. Underground water normally acquires the temperature of the ground in which it occurs, and probably, as a rule, this is equal to the prevailing earth temperatures of moderate depth; say 60° to 65° F. in Europe and 75° to 85° F. in tropical countries. On the other hand, much higher and much lower temperatures are frequently recorded. Water derived from melting ice on high peaks and protected to its outlet from contact with air may be much lower than average air temperatures; but temperatures higher than those possible through atmospheric agencies are less easy to explain. At times elevated temperatures may be due to some addition of deep-seated waters, for there is a terrestrial rise of temperature of around 1° F. per 50 ft. of depth, but in other cases it can only be attributed to chemical actions of which the oxidation of iron pyrites is probably the most common, as sulphur gases are so frequently present in hot springs. The thermal limestone springs of Sinai, Palestine, Mudros, and Macedonia all came under close observation during the war. Temperatures of 90° to 105° F. were

recorded. Those of Tiberias and Mudros were popularly frequented by the troops for bathing.

Limestone springs often have the property of petrifying objects placed in their path, and travertinous masses are deposited along the course followed by the water. Spring waters containing iron when subjected to aeration stain the rocks and vegetation with which they come in contact a red colour due to the oxidation and precipitation of some of the contained iron.

Some springs are liable to dangerous pollution where water enters highly porous or fissured rocks near habitations or farmyards, and the shallow wells of villages and farms yield notoriously bad water as a rule. It is, therefore, advisable in thickly populated districts to trace, if possible, the source of the water feeding the spring, and if this is not far distant or if in a region subject to injurious pollution the water should be analysed before use. Long distance travel may lead to the removal of impurities, but this is not certain, as water often traverses distinct channels after descent into open crevices, or "pot" holes, that at times reach a depth of 100 ft. or more in limestones and chalk.

During the war very accurate records were kept of the yield of many springs along lines of defence where supplies were important. The daily yields were graphed and their seasonal fluctuations, therefore, rendered very clear. Unfortunately in the confusion of removal these valuable graphs were lost, but attached are given the graphs of a number of Palestine springs which came under the close observation of an engineer officer. These indicate the extent of decrease and the influence of rainfall both as regards volume and time interval after rain. The Haifa rainfall is plotted in the same graph (see Figs. 1 and 2).

Shafts.—Excavating is usually a slow procedure. In hard strata the work is laborious and the results often uncertain, and in soft beds continued cavitation of material makes it essential to support the sides of the shaft. If undesirable upper water is struck its exclusion entails quite expensive and tedious processes of cementing or lining with cylinders. Under most conditions surface water can find admission during rains; objectionable matter often gains

access at the surface, and insects and small animals reach the water and die, creating dangerous conditions. When sunk in stream beds in flood areas they are usually filled with material or destroyed at each storm. Before an adequate supply can be obtained it is generally necessary to proceed

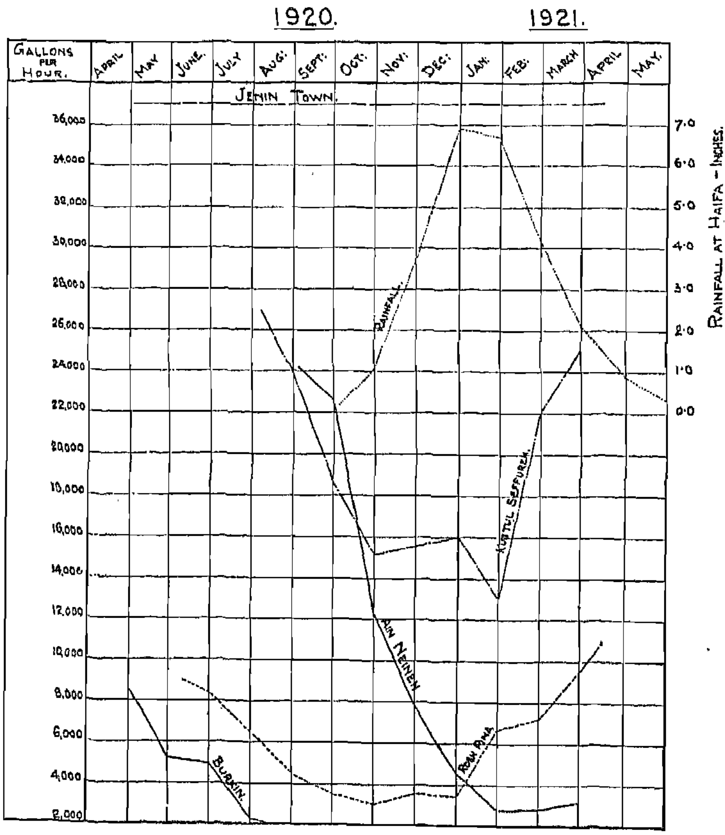

FIG. 1.—Yield of four springs in Palestine.

some distance under water, and much labour and apparatus is necessary to keep the works unwatered till finished.

Admittedly, there are regions where appreciable quantities of water can only be obtained by shaft sinking, the percolation by seepage being so slow that no form of bore-hole would be any use owing to the small infiltration and storage area.

Shafts may often be successfully sunk in stratified strata even if there is an absence of porous beds capable of yielding water in quantity. Provided there are interstratified bands of sandstone rock or a rocky mass is broken by sedimentation

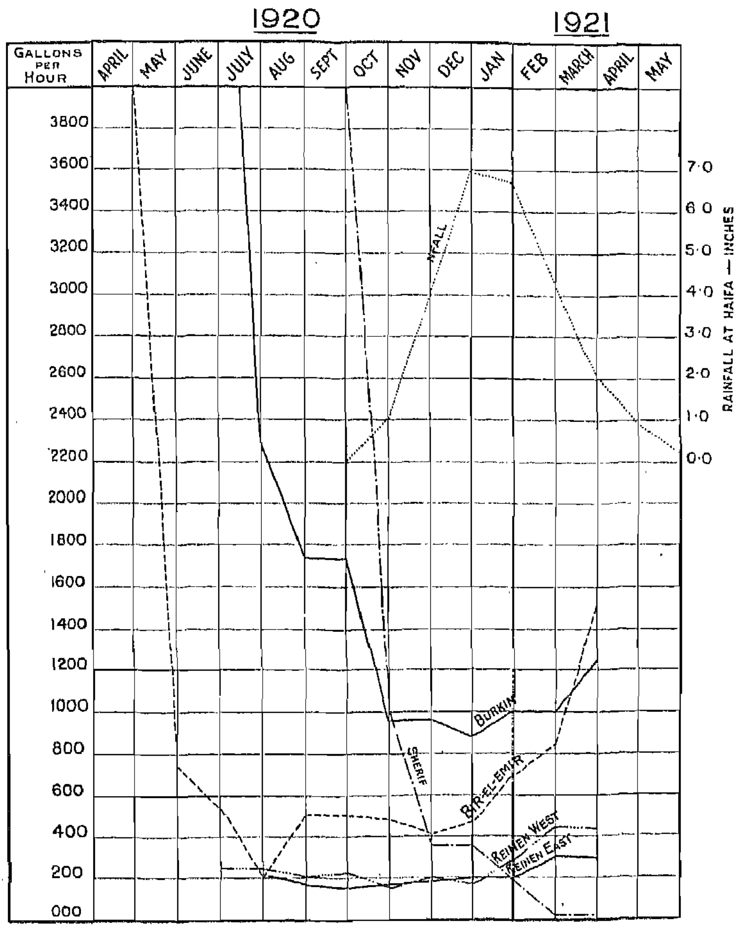

FIG. 2.—Yield of four springs in Palestine.

planes or joint cracks, there is always a fair chance of obtaining water. It will be noticed when sinking that long before any appreciable quantity of water is struck there is often a red oxidised zone of aeration, which gradually disappears after a certain depth until the true colour of the strata becomes

manifest. Sinking for a considerable distance may fail to develop more than mere trickles of water, but it will be observed that they all issue not as seeps or sweatings, but as jets from fissures or joint planes. As the depth of the shaft increases it may be noticed that any water struck has a higher pressure, and that it issues with greater force, so that if a moderate fissure is struck water may flow freely into the well.

At times water rushes into the well with violence when an important fissured system is pierced, but more often it is necessary to drive headings in the direction of water admission and so open up the feeder system. Hard sandstones or marlstones may in this way become large producers of water. It must be remembered that, with the exception of some unconsolidated tertiary strata, most fragmentary deposits have been compacted by pressure or cemented by intrusions of mineralised waters or by decomposition of mineral contents until they are incapable of permitting movements of water in their pores ; but, on the other hand, they have sustained such violent crushing and distortion that they have rarely escaped severe fracturing, and so furnished the necessary space for movements of fluids.

Through the absence of other facilities for obtaining water or the unsuitability of surroundings it may be impossible to avoid the sinking of shafts. For work in soft ground a lining of corrugated iron sheeting supported by timber struts has proved quite a useful expedient in the field. Steining, casing or lining wells with cement, usually entails too much time to be of much use in military operations. A temporary well may be lined with wicker-work, rushes, or plaited straw if timber is unobtainable.

Influence of Hygienic Measures.—It is doubtful whether the adverse influence of anti-malarial measures on water supplies in malarial war zones under certain conditions is fully appreciated. Where supplies are mainly dependent upon local absorption, as in hilly regions, the available yield of springs and wells may be seriously prejudiced by the methodical destruction of vegetation and the canalisation of all water-courses and damp zones. The concentration of efforts to drain water away as soon as it falls neutralises the operations of Nature, which interposes obstructions of all

PLATE VII.—A TYPICAL MACEDONIAN WATER-COURSE.
(Suitable for tube wells at all seasons.)

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PLATE VIII.—A FAVOURABLE LOCATION FOR TUBE WELLS IN GREECE.

kinds to delay and lengthen its overground passage and thus increases absorption. Anti-malarial measures within a sphere of prolonged occupation modified to a marked extent the yield of springs and wells along the Salonika front. Another feature that adversely affects the absorbent properties of some ground in hot countries occupied by troops is the treading down of the damp clay soil which, no longer protected by vegetation, bakes into a hard crust on the surface, thus resisting the entry of water during showers; indeed, only prolonged rains will soften the surface sufficiently to allow the admission of water.

The above influences only refer to specific conditions that are often repeated in Southern Europe and most tropical countries where mountain ranges of highly contorted crystalline and metamorphic rocks may become lines of defence, and where mechanical difficulties detract from schemes involving long distance transportation of water; when, in fact, all local resources are usually developed to the utmost. The exploitation of water supplies from little disturbed and little inclined sedimentary rocks where the contained water may have travelled laterally for many miles after admission far removed from the seat of military operations introduces less involved problems, and the above-named influences have no bearing on the water.

Hydrography of Macedonia.—In the exaggerated scale section attached all the main geological features will be seen. The nearly vertical, distorted, metamorphosed sedimentaries are unconformably overlain by inclined tertiaries, which are in turn unconformably covered by almost horizontal deltaic or valley deposits. In a central complex of crystalline limestones, quartzites, slates, etc., with dyke intrusions, water is only sporadically distributed, its presence being revealed by the issue of springs. The tertiaries, whose inclination rarely exceeds 20°, consist of red and white clays, sandy or gravelly clays, and slightly consolidated sands and gravel beds in which water is very prevalent. They are fed by percolation of rain water as well as spring water issuing from the metamorphics. Finally, the nearly horizontal delta and valley deposits of modern origin consist of stiff clays, sandy clays, and loose, unconsolidated sands and gravels (see Fig. 3).

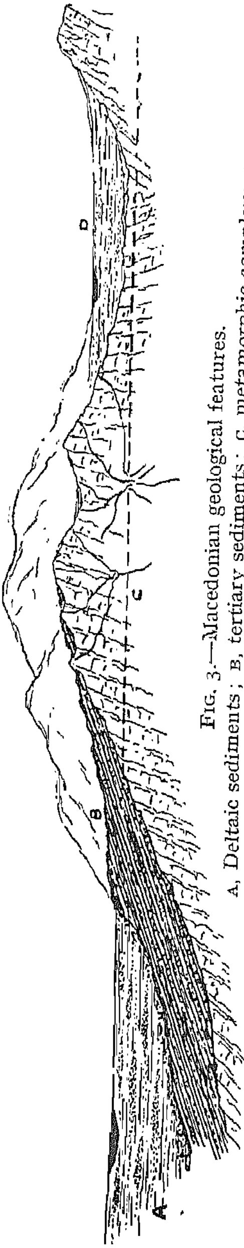

FIG. 3.—Macedonian geological features.
A, Deltaic sediments; B, tertiary sediments; C, metamorphic complexes; D, inland valley sediments.

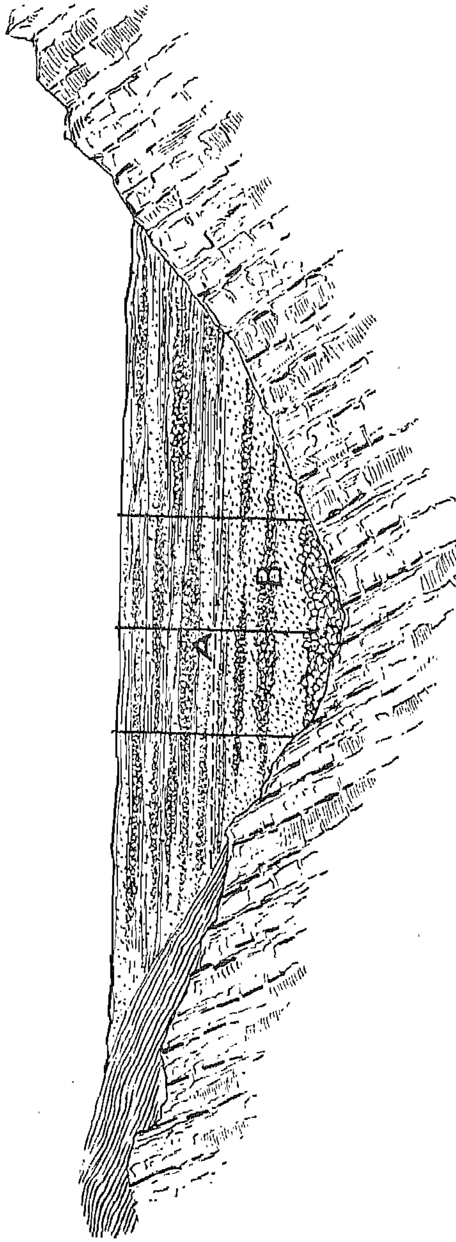

FIG. 4.—Section of contracted river course, where large yields of water were obtained by tube wells in bottom gravels.
A, Water level; B, level to which tube wells sunk.

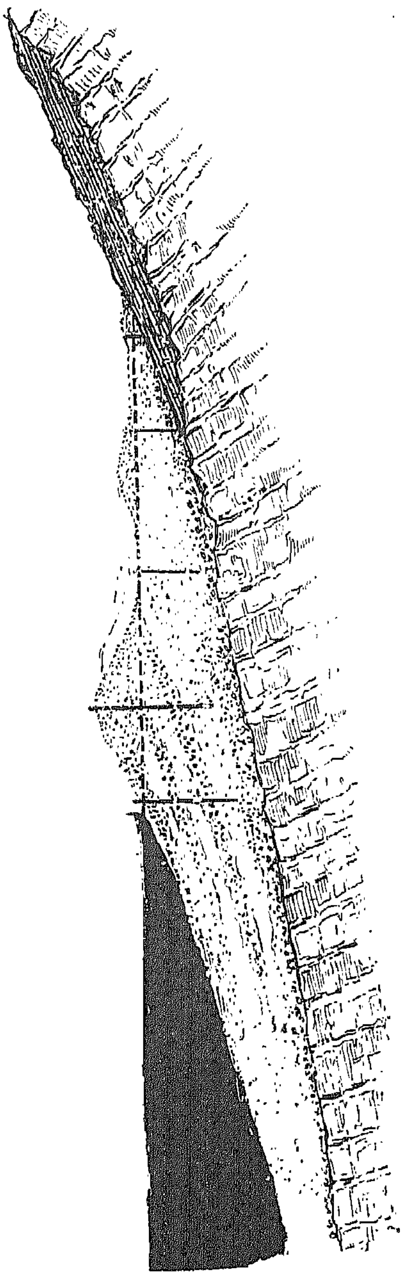

FIG. 5.—Coast section illustrating how fresh water accumulates in beach and dune deposits.

The water-table rises landwards, and is held up by the heavier sea water without mingling except along a belt of diffusion. Often fresh water may be obtained some distance out to sea.

Throughout Macedonia the valley and delta deposits and river courses have been developed by tube wells, the tertiaries by drilled wells, and the metamorphics have yielded the spring sources. As might be anticipated in such a coast line deposit of sediments in which gravels and sands are frequent, there is great lenticularity of the tertiary beds, as will be seen from the comparison of the well logs of three groups of wells located at Dautbali and Karaburun for collective pumping (see Figs. 9, 10 and 11).

The changing thickness and variable grading of the sands within brief distances result in very erratic depths, yields, and conditions of handling the wells. Thus one well completed in a coarse, open sand clears at once and gives a high pumping output whilst another alongside in a regular-graded and fine-grained sand may continue for weeks to yield a water turbid with sand particles or mica flakes, from which latter it may even never be entirely free. In some localities thick barren clays or sandy clays continue almost uninterruptedly for several hundred feet, and even sand lenticles embedded in such, or thick impervious clay bands, may fail to yield economically useful supplies of water although the static head may be very high. Artesian flows of 60 to 200 gallons per hour were struck in a number of wells of this type, and depression of head by pumping failed to increase the inflow materially. After pumping such wells dry the water-level gradually rose to the surface.

A tracing of geological events associated with the deposition of the tertiaries would lead one to suspect a lower and an upper sand or gravel zone. During the subsidence of the eroded, metamorphic land area a beach or littoral zone would gradually creep over the metamorphics as they sank, but as these earlier deposited beds became deeper and further from the land the series above would acquire a finer or deep-water character less suitable for water-supply purposes. Towards the period of maximum submergence there would naturally be less overburden of fine silts near the land area, and the most sandy zone would be nearest the metamorphics. On the re-elevation of the land successive shore lines would cause a sandy facies to encroach over the deeper-water silts, the thickness of

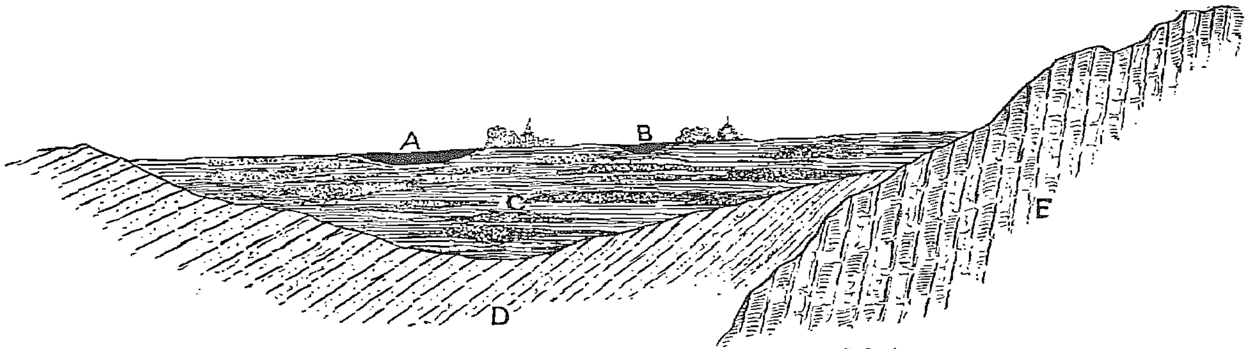

FIG. 6.—Section of Galiko delta (some miles from Golra).

A, B, Present water channels; C, deltaic sediments; D, inclined tertiaries; E, ancient distorted rocks. C Beds are suitable for drive tube wells; D beds yield water by drilled wells; E beds yield water only sporadically in fissures, so develop springs.

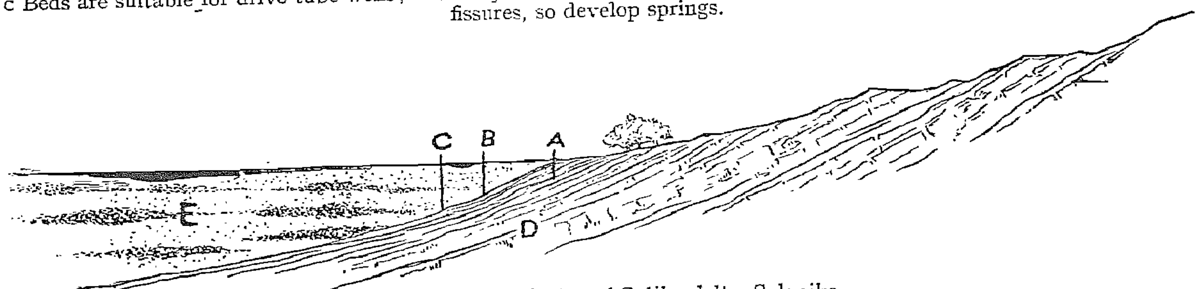

FIG. 7.—Section of edge of Galiko delta, Salonika.

A shaft sunk at A in tertiary beds, D, failed, whilst at B and C shallow tube wells yielded large supplies of water in the deltaic beds E.

which increases with the distance from the shore line of maximum submergence. Contemporaneous land erosion would naturally much reduce the thickness of those beds longest exposed to sub-aerial erosion. The sandy and even shingly and gravelly character of the beds in close proximity to the metamorphics proves the truth of the above interpretation of events.

At times fully-appreciated risks were taken in selecting well sites where near-by isolated inliers of tertiary beds gave some hope of success in much-desired elevated sites for hospitals, etc. In every case the wells proved successful, the suspected porous zone already described near the basal rocks being present. Several wells of very exceptional productivity derived their supplies from the junction beds of the metamorphic and tertiary beds, again emphasising the economic importance of the features described. The hydrology of parts of Macedonia has been entirely revolutionised by the successful solution of problems by the British Army during the war.

Artesian flows of water result when, owing to a capping of impervious beds, the water after admission to a porous stratum at a point higher than the site of the well, is maintained at a head exceeding that of the depth of the well. Only rarely does the text-book equivalent of artesian water occur in Nature, where a single porous sheet extending from hill to hill across a valley covered by impervious beds gives to the imprisoned water a head equivalent to the height of the outcrop of the porous stratum above the surface of the valley less that loss of head due to friction. In Macedonia, and, indeed, in most cases, no regular uninterrupted porous stratum continues for such distances as generally separate mountain ranges, but the artesian flow is due to the combined resistance of overlying beds and horizontal friction maintaining a sufficient head on imprisoned water to cause a flow.

The extreme sensitiveness of artesian wells in unconsolidated and incoherent sands was especially exemplified in the Vardar delta wells sunk for the Army and Salonika town water supply. If a rate of flow were induced which upset the equilibrium or stability of the sand-bed, the wells

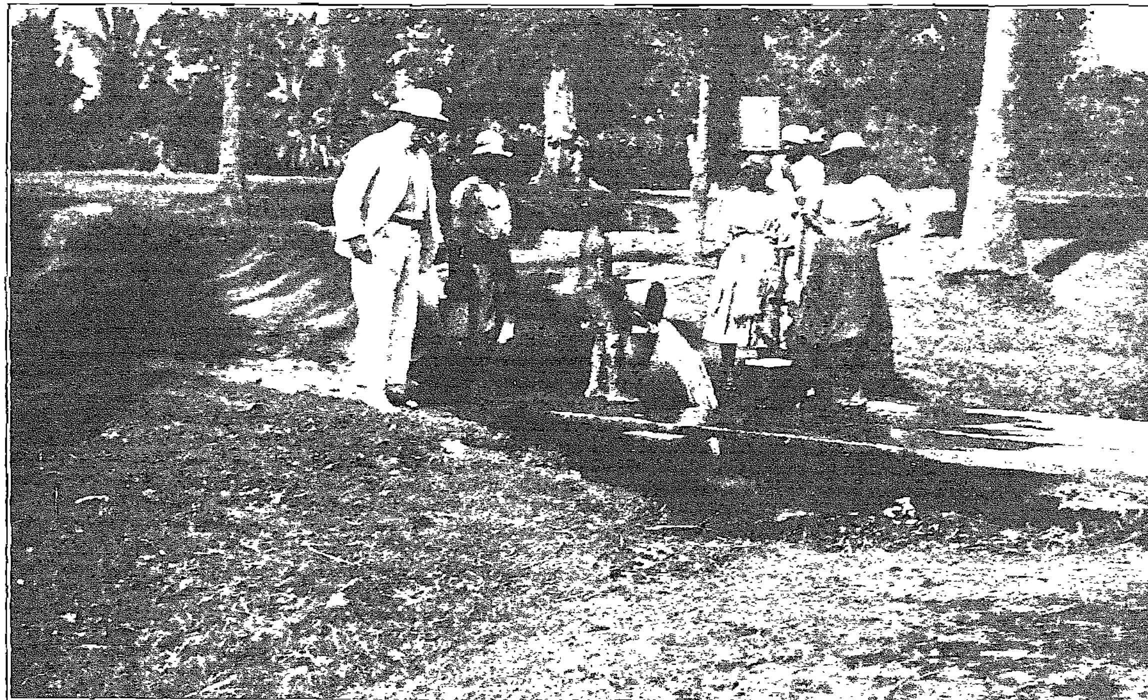

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PLATE IX.—ARTESIAN WELL IN BRITISH GUIANA.
Such wells may be struck on a large part of the littoral of Demerara.

silted up slightly and imposed a resistance that either stopped or reduced their flow considerably. It was, therefore, necessary to set the casing correctly in the sand and to adjust the level of discharge so that the maximum flow was obtained without disturbing the sand.

In the logs attached will be given many notes of interest that raise practical questions. One method employed for cleaning these delicate wells is perhaps worth describing. Several wells were so sensitive that the cleaning by bailers at the critical juncture became almost impossible owing to the agitation set up by their movement. A well flowing 2,500 gallons per hour would fall off to 1,000 gallons per hour, or even cease to flow as the result of a single trip of the bailer or the movement of the casing a few inches. In order to avoid such agitation a column of 2-in. pipe was lowered into the well. Coupled to a flexible hose at the surface, the tubing could then be raised or lowered at will by means of a suspension rope whilst a flush of water was being maintained to wash away any influx of sand.

An interesting and unexpected difficulty arose when drilling in the tertiaries at Karaburun, some miles south of Salonika. A geological inspection led to an unqualified statement concerning the practical certainty of finding water by drilling for some projected hospitals, although the Greek and French forts in the district relied exclusively upon water carried by barge from Salonika. Water was

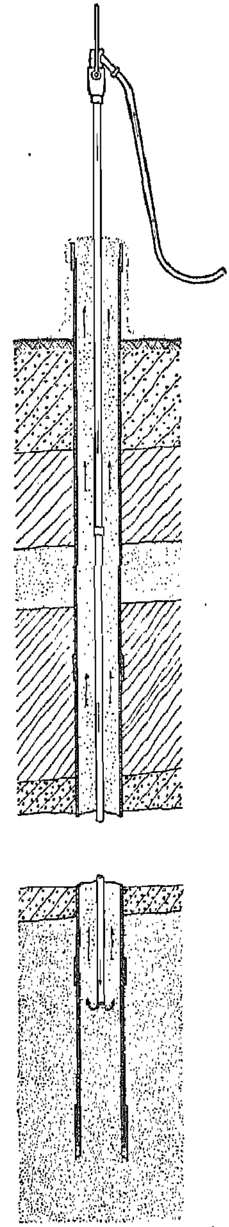

FIG. 8.—Arrangement for flushing sand in artesian well.

subsequently struck in a well at the anticipated depth of about 170 ft., but a little deeper, between 200 and 250 ft., a water was struck containing large quantities of Epsom salts (magnesium sulphate), quite impossible to drink. As the urgency was great and considerable expenditure had been incurred in reliance upon ample supplies of potable water being procurable, much concern was naturally expressed. Although no impervious separation beds had been noted in the well, conditions led to the supposition that a fresh water zone might overlie the saline deposits just above sea-level. A new well was hastily commenced a few hundred feet away, and all daylight hours worked, with the result that in three days a yield of 1,000 gallons per hour of good water was struck at 150 ft., and the well only carried to 184 ft. On the fifth day an engine and pump had been erected and were working. This well continued to yield potable water up to the cessation of hostilities, as well as many others sunk in the district.

Considerable areas are covered by a thick deposit of red clay in which shingle and pebbles occur almost throughout; such an intimate unsorted deposit suggests glaciation. Several wells were drilled into these sediments with the result that small yields were obtained at shallow depths from horizons containing more gravel than usual.

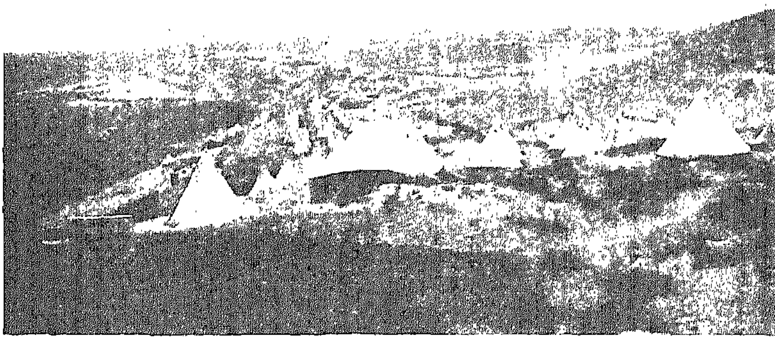

PLATE X.—ITEA REST CAMP: GULF OF CORINTH IN DISTANCE.

This camp was fed by water pumped from tube wells and drilled bore-holes located in the plain observed below, fringing the hills from which numerous springs issue

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PLATE XI.—NATIVE WATER WELL IN SUDAN.

Sunk into decomposed granite far removed from any sedimentary rocks.

CHAPTER III

DEVELOPMENT OF WATER SOURCES

Development by bored or driven wells—Evaporators—Filtration—Development of springs—Sundry emergency expedients.

Development by Bored or Driven Wells.—Both these systems are dealt with in detail in the following pages. Their limitations should, however, be fully realised, as in France much *disappointment was felt in consequence of the small yields* of bore-holes. Drive tube wells can often be multiplied to such an extent that in the aggregate the volume of water obtained is very large, but such is not possible with bore-holes, where the water-level is often very far below the surface. From bore-holes striking a subterranean fissured system in chalk, limestone or marlstone, very large yields may be obtained, and the same applies to the case when very coarse sands, sandstone, gravel beds, or flint layers of large extent occur below a defined water-table. In the Macedonian tertiary sediments very irregular yields were obtained from the lenticular bodies of sand pierced. Yields of 1,000 gallons per hour from wells 6 in. to 8 in. diameter were about the average that could be safely anticipated for long periods. In specially favourable cases yields of 5,000 to 10,000 gallons per hour were reached, and natural flows up to 2,500 gallons per hour were obtained in certain delta deposits. In some cases low yields were undoubtedly attributable to the plugging of the pipe perforations where the even grade of material led to this result. One case was specially noteworthy where, for geological reasons, it was practically impossible to accept the poor results achieved. On raising the casing and inserting a larger column with more perforations a considerable yield resulted at a less depth.

Fine unconsolidated sands never yield up their water contents freely, but if sand screens are used there is usually a benefit, as the continual withdrawal of finer material from an unsorted type leaves a coarse residue around the well which in time creates the equivalent of a sump by which the percolation area is largely increased. Those in charge of water

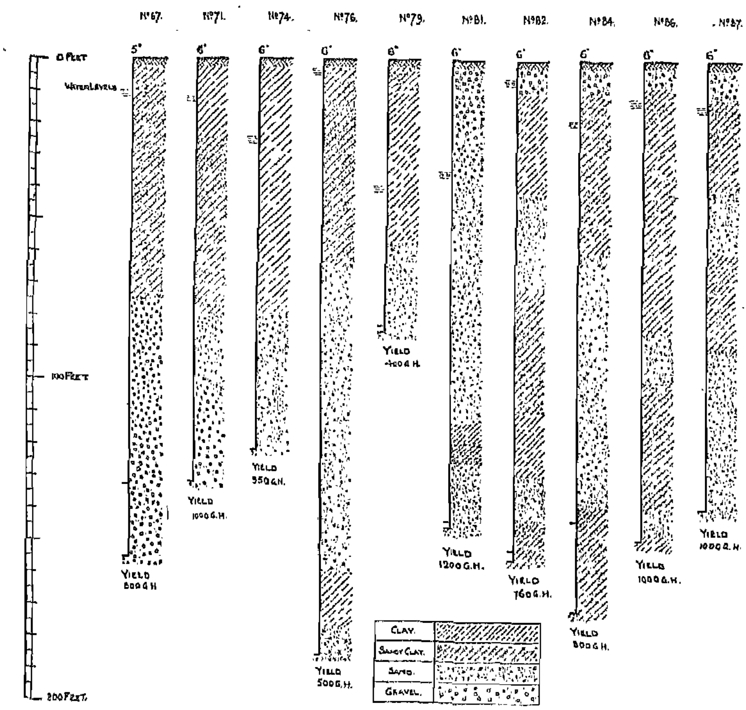

FIG. 9.—Sections of ten grouped bore-holes at Dautbali, Salonika, showing wide differences of strata, depth, yield of water, and static level of water, although located within 150 ft. of each other and at same elevation.

supplies should, however, keep this feature of limited yield in view when arranging the methods of watering large bodies of troops or animals. Often it is only deep wells that can be relied upon for the extraction of water, and the possible restricted yield of individual wells must not be lost sight of.

Just as a single failure should not be taken as proof of the absence of water so should one large producer not be

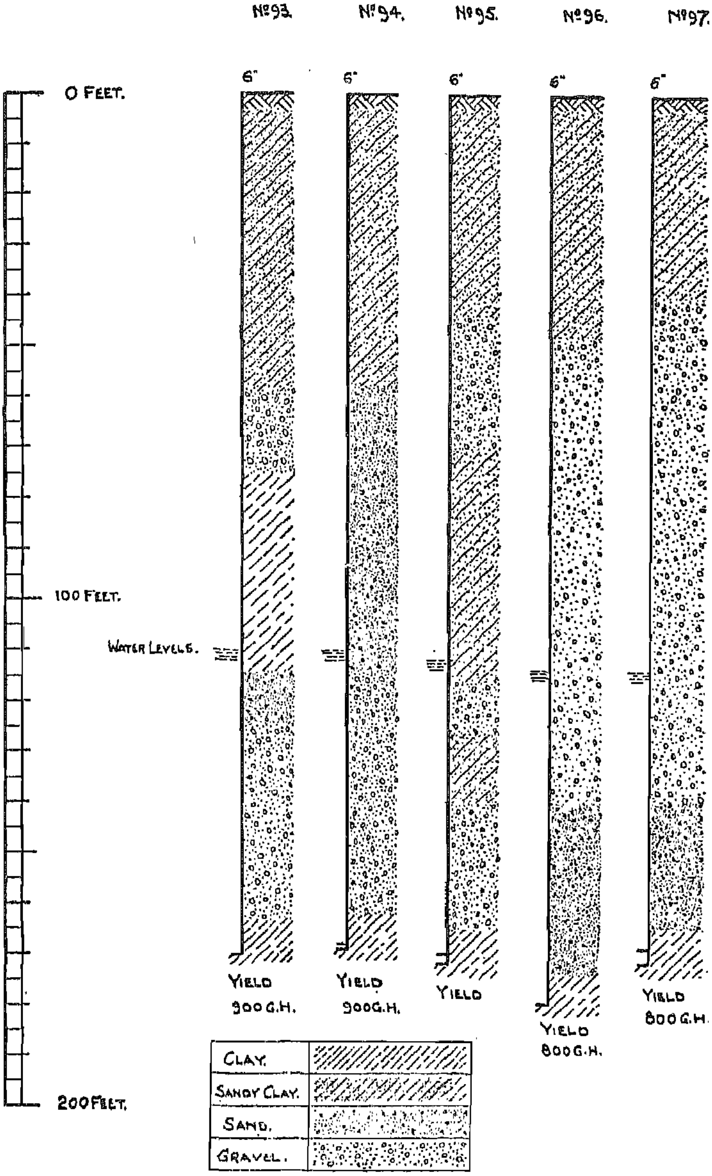

FIG. 10.—Sections of five of a group of ten bore-holes drilled at Karaburun, Salonika.

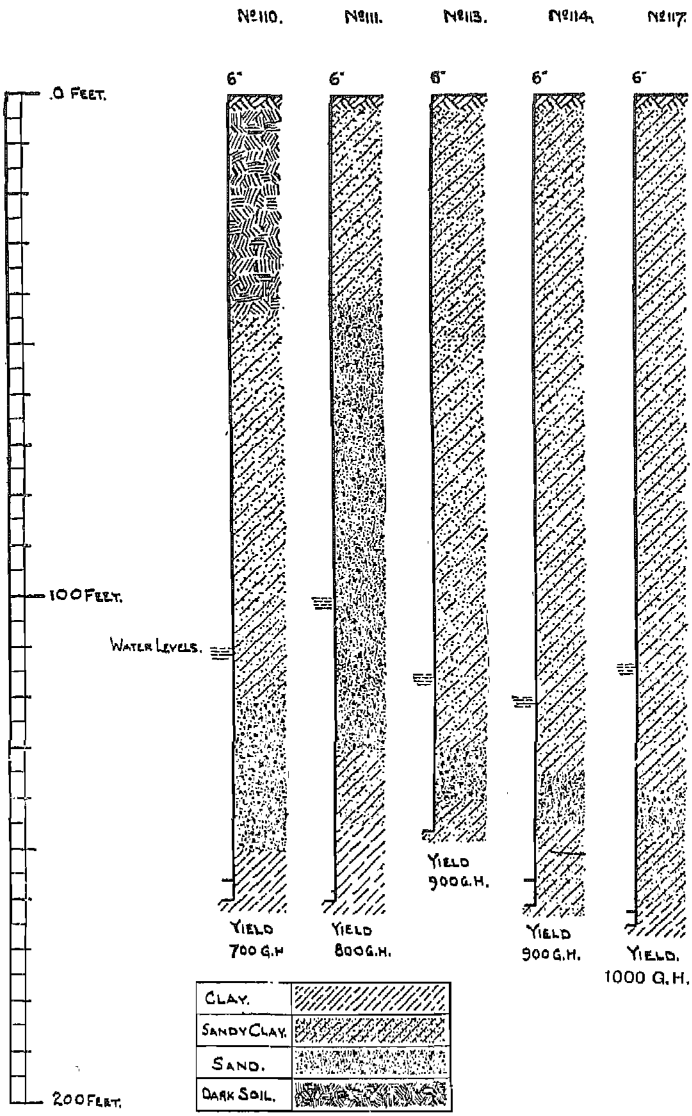

FIG. 11.—Sections of five of a group of ten bore-holes drilled at Karaburun, Salonika.

taken as an indication of future yields. The deposits of sand vary so much in character and extent within short distances that amidst estuarine and littoral conditions no two wells give concordant results. In order to illustrate this feature the sections of ten wells sunk within a distance of 150 ft. of each other in a group near Salonika are shown in Fig. 9. It will be immediately observed that the thickness and kinds of sand and gravel vary, the depths are different, and the static water-levels and pumping yields show no consistency. This example is especially illuminating, as it is rare that so many wells are sunk within such a small radius, but in this case a large aggregate volume of water was required for military base purposes, and it was from the first realised that the necessary quantity was only procurable by multiplying the units.

Two equally interesting groups of ten wells were similarly drilled at Karaburun on the Salonika Gulf, in the tertiary sediments where also widely-differing features manifested themselves. The sections of one group are shown in Figs. 10 and 11.

Evaporators.—In some places where potable waters are almost non-existent reliance is placed upon the evaporation of sea water. Naturally any boiler and condenser can be utilised for obtaining water in this way, but it is a costly operation in fuel consumption, as only 7 to 10 lbs. of condensed water are obtained per lb. of coal used, and the boilers need constant cleaning out. To avoid these losses multiple evaporators are used in which as much as 35 lbs. of water can be obtained per lb. of coal. Steam generated in a first unit is used to evaporate water in a second unit at a reduced pressure by yielding its latent heat during the process of condensation. The steam raised in the second evaporates water in a third at further diminished pressure, and that in turn in a fourth, till in the last unit evaporation proceeds under a high vacuum and consequently low temperature. In a fourfold unit of modern design $3\frac{1}{2}$ times as much water can be obtained as in a single boiler and condenser, so that with an ordinary Cornish boiler 35 lbs. of water can be obtained from the combustion of 1 lb. of fair quality coal.

The evaporators are designed so that the deposited salt can be quickly and easily removed at intervals.

Filtration.—River waters may be rendered fit for safe consumption by combined sedimentation and filtration. Water containing much sediment may be conducted into large chambers where the velocity is sufficiently reduced to cause precipitation of suspended particles. Very finely divided inorganic particles may only separate out after long, quiet settlement, and certain organic impurities can only be removed by treatment or filtration. Effective sedimentation has been accomplished by passing the water along spiral chambers in which the motion is frequently changed or reversed, causing velocity checks that lead to the deposition of suspended matter. Movement along tortuous channels promotes quicker sedimentation than complete stagnancy, during which algæ growths may develop.

Filtration not merely removes suspended particles, but on a suitably designed filter-bed formed of graded sand and gravel, glutinous growths of bacteria thrive which destroy organic organisms. A filter-bed improves in bacterial efficiency with age, but diminishes in capacity, and for this latter reason it is necessary to clean out filter-beds periodically. Upon a masonry or brick basework a bed is built up starting with a foot of coarse gravel and following upwards with layers of a foot of less coarse gravel, sand, and finally fine sand. Water is usually distributed over the filter by a spray to cause aeration, and the clarified water is drawn off from the base gravels through perforated pipes evenly spread over the whole floor of the filter-bed to ensure the full filtering medium being utilised.

Normal filter-beds are allowed to work at a rate of from 1 to 3 gallons per square foot, say 4 in. descent per hour according to the nature of the water being treated, and when the rate of percolation is reduced to an unserviceable amount the upper inch or so of sand is either raked over and cleansed with a water flush or removed and replaced by washed sand.

Obviously such filter-beds occupy considerable space if designed to handle large volumes of water, and their cleansing is costly in labour, and objectionable, as men have to work on the filter-bed itself. The filter-beds themselves owe their efficacy mainly to the formation of slimy gelatinous

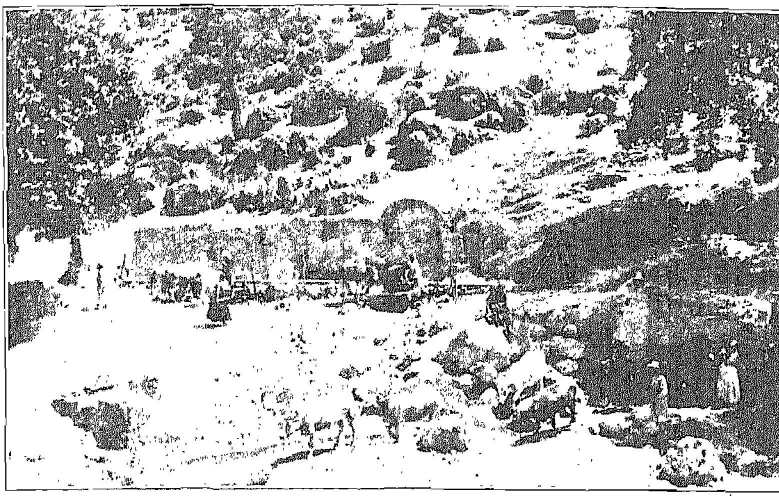

PLATE XII.—MACEDONIAN SPRING.

A large limestone spring used by Macedonian peasants, from which a pipe line was laid to a distant military camp.

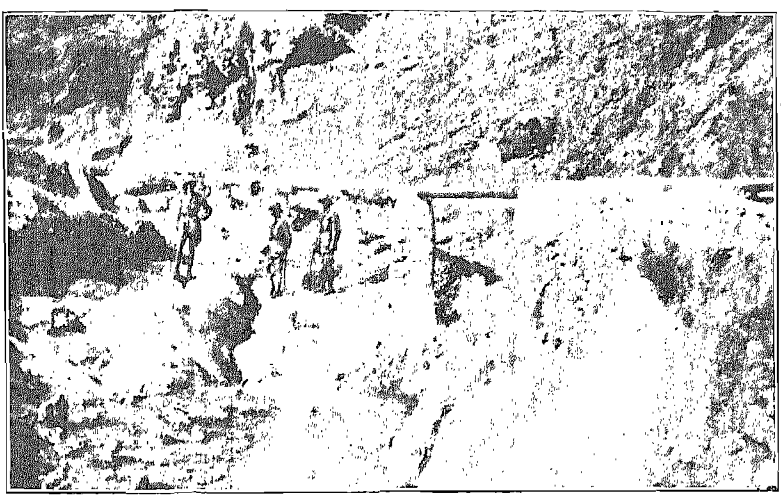

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PLATE XIII.—DEVELOPMENT OF MACEDONIAN SPRING.

Spring tapped at its source in a limestone gulley and led by pipes and masonry conduit to distance.

colloidal substances which in time coat the granules of sand and gravel, and to this material bacteria contained in water adhere during its enforced contact with the grains in its descent. In much the same way it is believed that the earth purifies waters which have been polluted by surface sewage or manures on agricultural lands. It is claimed that the passage of polluted water through 3 ft. of earth may often remove all objectionable bacteria.

Emergency water supplies rarely justify the construction of such costly and bulky means of filtration, and even for permanent installations it is now more usual to install the modern mechanical filters which with the aid of an artificial precipitant and mechanical devices allow much larger quantities of water to be passed through in a given time, as well as furnish means for rapid cleansing when circumstances demand.

So-called mechanical filtration is commonly performed by first treating the water with a cheap and harmless precipitant, like alum, to the extent of about 1 grain per gallon, and after settlement passing the same under pressure through a vessel in which sand has been spread. Sulphate of alumina has the peculiar property of causing the rapid precipitation of sediment by the formation of a colloid by reaction with dissolved calcium carbonate, and this colloid not only carries with it in its descent suspended mineral matter but also micro-organisms. It even possesses decolorising properties, and by reaction with peaty acids will speedily cause some clarification. After a brief period for sedimentation in a settling chamber the water is led direct to the mechanical filters where, under a pressure varying from around 10 ft. in some designs to over 200 ft. per head in others, the water is driven through sand filters. When the filter becomes plugged and a great loss of head is manifested the inflow is checked, and the sand is washed by a reverse flow of water through the sand, whilst a stirring device agitates the sand. Some 10 to 15 minutes' washing usually suffices to cleanse the sand, and a further period up to half an hour may be necessary before a skin is re-formed that ensures a re-establishment of the standard purity of water. In the case of the Jewell filter about

5 per cent. of the water may be wasted in cleansing and re-establishing the desired standard with a loss of less than 2 hours out of the 24 hours. The filters are arranged in units so that each can be cleansed in rotation without rendering the delivery intermittent. Naturally the interval between successive cleansing depends upon the nature of the water and the volume put through, but a rate of filtration of from 70 to 100 gallons per square foot per hour can be passed through. Units of 5,000 to 10,000 gallons capacity per hour are generally adopted, and a single attendant manipulates each filter in succession.

Some types of mechanical filter dispense with a chemical precipitant and rely upon oxidation by some oxidising agent for purification after precipitation of sediment. In the Candy filter water, after being filtered by passage through crushed silica, passes through a spongy iron-oxide and silica compound possessing abnormal properties of filtration and oxidation. In addition to the removal of pathogenic bacteria the reduction of ammonia and nitrates is noticeable. The filter is cleansed by a reverse flow of water like the sand filters. The two products "polarite" and "oxidium" used in the Candy filters do not lose their properties with continued use, having the power of re-absorbing oxygen from the air after use. Only about one-fifth to one-tenth of the quantity of water is required for cleansing the Candy filters as with the sand type.

During the great war mechanical filters were used in Egypt for the purification of Nile water before transmission by the pipe line from Kantara.

The Development of Springs.—Amidst surroundings of sedimentary rocks, springs issue along a line of outcrop where porous strata overlie an impervious bed. The important springs of the lower mountains of Macedonia largely originate from the limestones, which are a prominent feature of the older disturbed rocks. Many issue at quite high points, and their volume and constancy is often a theme of speculation in conversation. Yields of several thousand gallons per hour are not uncommon, whilst smaller ones of a few hundred gallons per hour are extremely numerous.

In many parts the highly inclined, faulted, and contorted

PLATE XIV.—GRECIAN SPRING.

An enormous limestone spring used for irrigation of cotton and corn lands near Bralo, Greece.

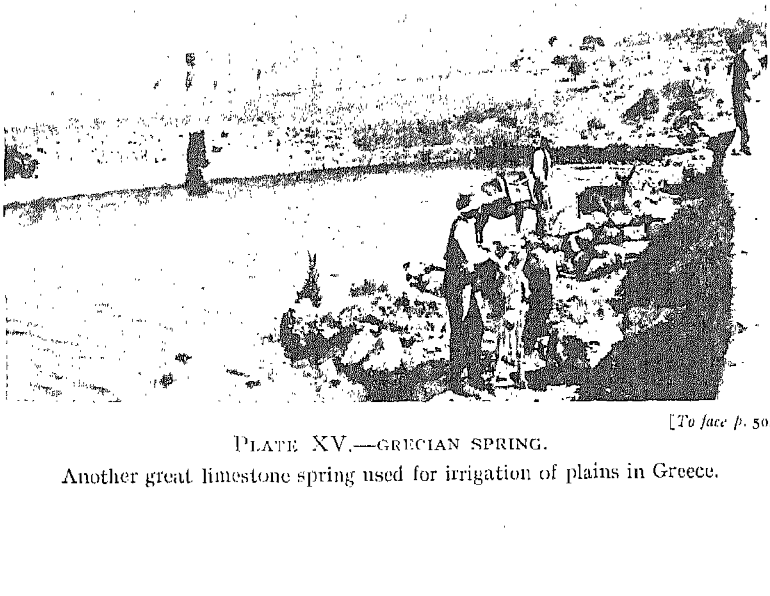

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PLATE XV.—GRECIAN SPRING.

Another great limestone spring used for irrigation of plains in Greece.

limestones readily admit rain water along disturbed or fractured belts in which solution channels are formed during its circuitous movement to some point of outlet far removed at a lower level. Centuries of such action result in the creation of vast subterranean receptacles where exceedingly intricate channels are produced by the solvent action along joint cracks or fault planes favouring dissolution. So hard are many of the waters emerging as springs that lime is freely deposited on all surrounding material as a tufa. The reason why water finds admission over a wide area whilst its exit is restricted to a few points of small dimensions is that, whereas rain water entering the rocks is chemically active through the presence of carbonic acid absorbed from the air, that leaving is inactive as it has dissolved its full capacity of lime after entry. This property and the intricate system of passages it is compelled to negotiate before finding an exit leads first to its accumulation in chambers of increasing size and afterwards to its slow discharge from some point which is not enlarged lower down on the hill-side.

Many such springs were enclosed by a concrete chamber built upon the rock with a single outlet pipe. Occasionally water issued or oozed from a series of points that it was difficult to concentrate to a single spot ; such were often very successfully handled by draining or driving a heading into the hillside. Usually the whole supply was then deflected into a single sump that could be totally enclosed by masonry. Quite surprising yields resulted from this form of treatment of some unimposing seepages. One unattractive spring gave 2,000 gallons per hour on opening, another 1,500 gallons per hour. A seepage bank near Salonika gave under treatment 1,000 gallons per hour.

A very wonderful spring which had been developed by the Bulgars near the summit of Grand Couronne Doiran was flowing freely on its capture during the August campaign of 1918. Two enormous limestone springs in Greece near Bralo are shown in Plates XIV and XV. Near Itea, on the Gulf of Corinth, there are several flowing at a rate of over 30,000 gallons per hour, but usually the water is too saline for pleasant consumption. The Daūtbali Spring, yielding 5,000

gallons per hour, was conducted by a pipe line to the Salonika base area (see Plate XIII, p. 48).

Sundry Emergency Expedients.—Under some conditions of extreme privation men and animals may be kept alive by utilising vegetable products, such as water-bearing creepers, melons, coco-nuts, etc. In many tropical jungles, certain creepers whose foliage is confined to the tops of the forest trees derive their sustenance through long, straight, hollow stems which are filled with water drawn upwards from the earth. The vertical drag is so powerful that if cut near the ground the air rushes into the root and the contained water is carried upwards out of reach. By cutting high up, and then a few feet lower, a strip of stem is obtained containing water, which can be drunk or allowed to run into a vessel. On one occasion in West Africa the author was enabled to keep an exploring party alive for several days by their use before water was discovered.

Water melons will support both animals and men for some time if abundant, and the water or "milk" of coco-nuts can be similarly used. In parts of the Sudan a tree called Tebeldi (Baobab) with a large trunk is hollowed out and filled with water in the wet season. Along trade routes where no water exists thousands of trees are utilised in this way, and the water is sold to passing travellers. So important is this source that in the province of Khordofan all tebeldi trees are registered, and their contents recorded for official guidance. These tree trunks are filled by hand during the brief rainy season by ladelling water into a hole near the lowest main limbs. After filling from a sump at the foot of the tree the orifice is covered with clay to prevent the admission of life. Their capacities vary from 300 to 1,000 gallons of water, which remains fresh and cool for long periods.

Mules, horses, donkeys, camels, and elephants are sometimes used for conveying water long distances. Special copper or galvanised iron vessels of suitable shape and capacity are used, and these can be simply strapped to the backs of animals. Water-bags and skins are also employed in the same way. The Australian water-bag is made of canvas through which there exudes sufficient

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PLATE XVI.—SUDAN (KHORDOFAN) WATER SUPPLIES.

A typical hollowed baobab tree, showing admission hole and notched stick by which the owner reaches the lower limbs.

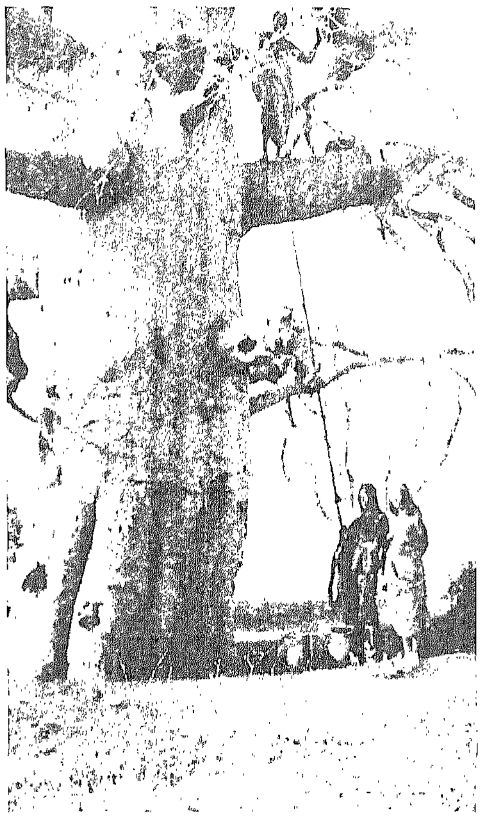

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PLATE XVII.—SUDAN (KHORDOFAN) WATER SUPPLIES.

Water being removed from hollowed baobab tree in skin by native, and lowered to the women purchasers below.

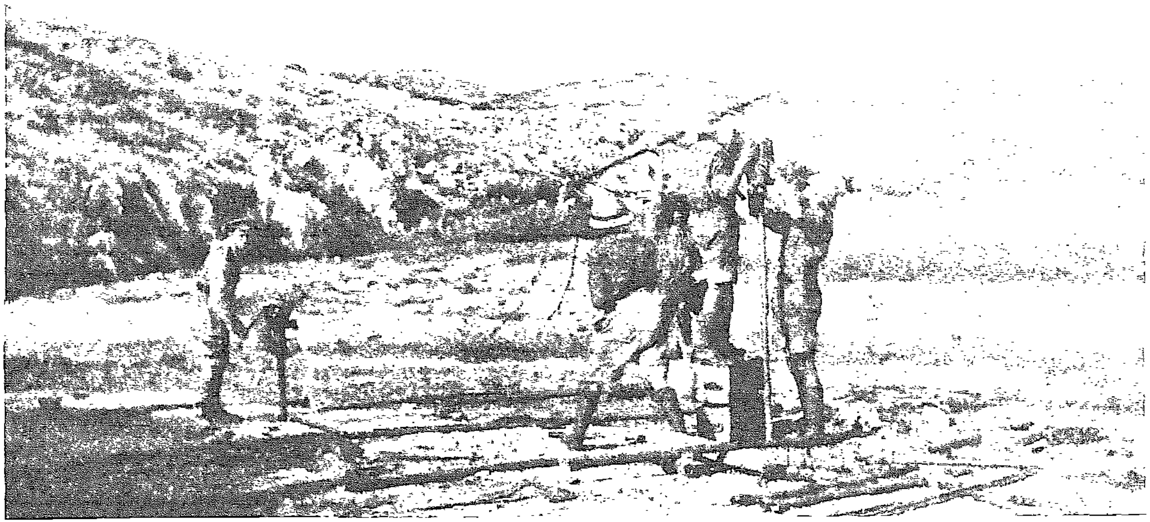

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PLATE XVIII.—GROUP OF TUBE WELLS AT KAKU DERE.

water to allow evaporation that keeps the contents always cool. In a hot, dry wind the water may be reduced 20° to 30° below the prevailing shade temperature. The losses are naturally severe in such cases, and the use of these bags is confined to regions where supplies can be frequently replenished.

Important expeditionary forces have been watered solely by animal transport, where a single breakdown in arrangements would have imperilled the life of all concerned. Such has been the case with military advances in Somaliland, Egypt, the Sudan and Arabia, and during the Great War many lives were sacrificed in punitive and intelligence expeditions into deserts where water wells were few and far between. As the loss of water in long desert journeys means often certain death, it would appear needless to warn travellers against leaving the control of water in the hands of any but the most trustworthy. In the belief that Allah will provide, or, perhaps, rather that the Europeans can lead them out of all troubles, the Arab is sometimes tempted to waste the one link between life and death.

CHAPTER IV

DRIVE TUBE WELLS

Uses and limitations of drive tube wells—Description of apparatus—Process of driving a tube well—Testing yields—Selection of sites for drive tube wells—Grouping of tube wells—Purity of sub-soil river waters—Record of results.

Uses and Limitations of Drive Tube Wells.—Sub-soil waters in unconsolidated sediments can often be tapped by what are commonly known as Tube Wells, Norton Tube Wells, or Abyssinian Wells. They were originally patented by a Mr. Norton in England, and were subsequently employed in the Abyssinian campaign of 1868. Norton tube wells have always constituted part of the equipment of the R.E. field companies in the British Army, but their utility has been undervalued owing to their frequent failure in the field. The advantages of tube wells over the sinking of shafts may be classified as follows:—

(*a*) Simplicity.
(*b*) Speedy construction and withdrawal.
(*c*) Cheapness.
(*d*) Ease of dealing with incoherent ground.
(*e*) Exclusion of undesirable surface water.
(*f*) Protection from surface pollutions.
(*g*) Impossibilities of tampering with water.
(*h*) Quick cleaning of water through screening.
(*i*) Protection from a surface flow or flood.

Tube wells can be driven by 3 to 5 men in unconsolidated sediments at a rate varying from 3 in. to 1 ft. per minute. The average time of sinking wells averaging about 20 ft. in depth being usually less than 1 hour, say 3 to 5 men-hours; whereas a surface shaft under similar conditions generally entails about 60 times as long—360

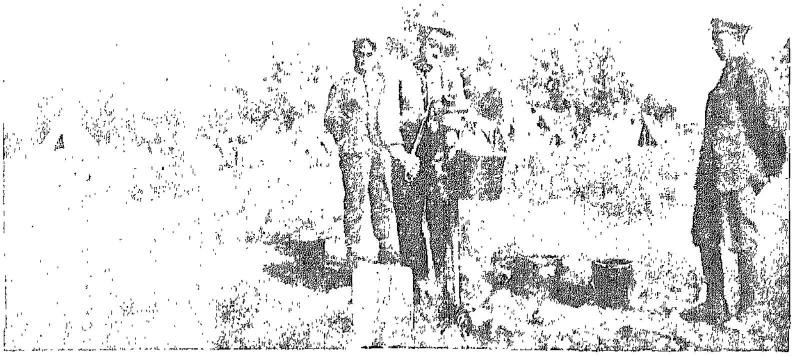

PLATE XIX.—TUBE WELL DRIVEN IN H.Q. CAMP.

One of many sunk in the course of a single day after the landing of a division in destroyers at Dedeagatch, Bulgaria.

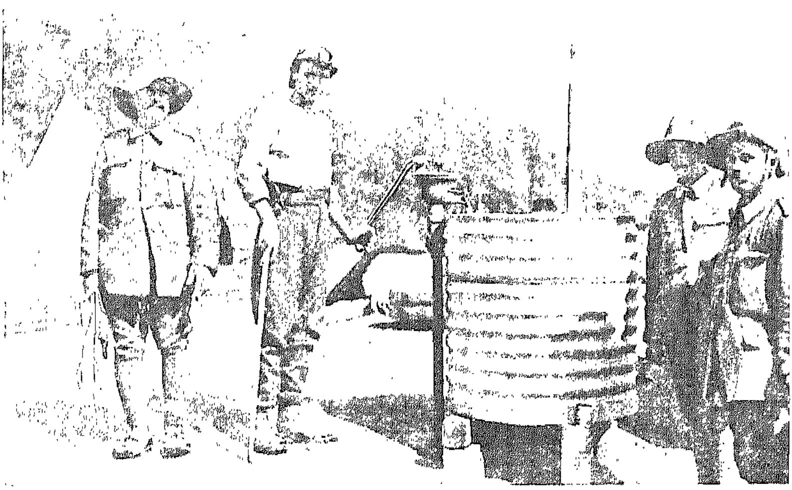

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PLATE XX.—ARRANGEMENT OF TUBE WELL AND TANK AT DOIRAN RAILWAY STATION.

men-hours—with timbering for supports, laborious raising of a considerable quantity of excavated material solely to provide space for the men to work, and other objections. When water is reached, there are further difficulties associated with its extraction to allow work to proceed, and often the continuous inflow of sand or caving of the sides near the water-level makes further progress difficult, if not impossible, under field conditions. In any case, without somewhat intricate precautions involving the use of cement, cylinders or other means, it is impossible to isolate any undesirable upper water from that below, and there is always the danger of the well collapsing through rotting timbers, land settlements, or other causes.

By means of a tube the upper water, most liable to contamination, may be passed and shut off, and sources can be tested and passed at any point without danger to the support of the well. The well cannot be tampered with or sustain any damage below ground, and it can be withdrawn at any time and re-inserted elsewhere. If one well fails, others can be sunk at no extra cost other than the labour involved in the operation, and surface pollution is often impossible. This latter claim is sometimes questioned, but is subject to qualification only in few cases, such as when driving into river gravels, or beds where there are no intermediate layers of clay, fine sands, or impervious matter to prevent water thrown on the surface reaching the stratum below. Ordinarily ample proof is afforded of the tightness of the joint by vigorously pumping the well, when, if not inserted into the water stratum, a high vacuum can be maintained, and water placed around the well at the surface will not be drawn into the ground or even percolate away except when sands occur at the surface.

The driving of successful tube wells is a much more scientific operation than is popularly supposed. Experience has shown that many of the recorded failures were due to ignorance of the operators, and were not attributable to the system. Time after time success has rewarded persistent or scientific efforts where nothing but failures had been previously recorded. Failure to appreciate the limitations of tube wells and abuse of their employment is the usual

cause of non-success. The following essential conditions must be fulfilled :—

(1) Strata must not be too hard to resist the effective penetration of a pointed tube.

(2) If the water is not under a "head" they are useless, without modification, if driven beyond 20 to 25 ft., as the water cannot be raised by a suction pump, and their dimensions do not admit of the insertion of a deep well-pump.

(3) There must be beds of sand or gravel with sufficiently large voids to admit the free entry of water into the tube as fast as it is abstracted by pumping.

Description of Apparatus.—Tube wells consist of a succession of lengths of tubing to the bottom of which is attached a perforated length with a pointed base piece that enables it to pierce and compress yielding strata when driven by a monkey or hammer. A tapered steel point is generally employed to resist impact upon hard pebbles that may obstruct its progress or to break through thin layers of hard material. As each length of tube is driven down a new length is attached until the desired depth is attained or further progress is checked by resistance. Tubes of $1\frac{1}{4}$ in. to 2 in. diameter can be driven into unconsolidated sands, gravels, soft clays, marls, and sandy clays, but not in hard shales, sandstones, limestones, conglomerates, and such-like compact bodies. Some unconsolidated beds, as fine sands, resist penetration much more than others; indeed, it is surprising to what an extent certain fine and compacted yet uncemented sands resist compression. Under exceptionally favourable circumstances tube wells may be driven to 100 ft.

Although it is unusual to drive wells when the water-level is below 20 ft., deeper waters can be raised by sinking a shaft and fixing a lift and force pump at a suitable depth.

Points.—The point of a tube well consists of a 4 to 5 ft. length of perforated tubing, into one end of which is inserted a mild steel wedge-shaped point. This may be screwed or shrunk on the outside or inside, or otherwise conveniently attached, the only essential being that its exterior diameter must neither be less than, nor appreciably in excess of, the

PLATE XXI.—DRIVING A TUBE WELL.

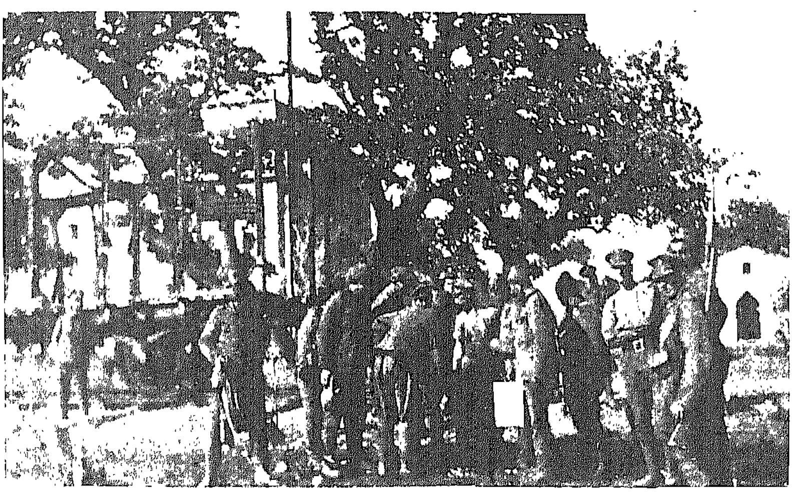

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PLATE XXII.—SCENE ROUND A TUBE WELL WITHIN A FEW MINUTES OF COMPLETION, DEDEAGATCH, BULGARIA.

sockets of the piping. If smaller, a clear passage is not made for the tubing, and if larger there is danger of the wells being polluted by admitting surface or undesirable waters around them. If too sharp, the point is liable to fracture on striking a hard pebble, and if too blunt its progress is unnecessarily impeded ; consequently, a happy mean should be struck. The same arguments apply to hardening, a medium temper being preferable. A square shape is preferable to a hexagonal, octagonal, or round point, as the edges of a square present a good cutting medium if the tube is rotated, as is sometimes an advantage during driving.

Drive points are perforated for a distance of from 2 to 5 ft. above the point. In most cases 2 to 3 ft. suffice if the perforations are closely spaced, but the tube must not be too weakened by perforations or it will suffer collapse under driving. As the object of the orifices is not merely to permit the entry of water but to restrain the admission of sand and particles that would plug the piping and exclude or restrict the inflow of water, discretion is needed to determine what sized perforations should be provided. Each case should, in reality, be decided on its merits, as the sand particles vary so much in size and character. Uniformly fine sands can only be held back by screens, whereas gravels or coarse shingly material would enable ½-in. perforations to be used, but generally sands are of a mixed type, consisting of a mingling of fine and coarse material, and this property is especially welcome where tube wells are concerned.

Sand Screens or Strainers.—Tube wells are rarely successful in other strata than sands or gravels, as the rate of inflow through more consolidated material is too slow to supply the needs of a suction pump. When a mixed grade sand is tapped and pumping is commenced fine grains are first drawn in with the water, then coarser and coarser particles appear as pumping is continued until a natural filter is produced by the retention around the tube of grains that will not penetrate the orifices of the screen. The final grouping of the filtering sands is determined by the size and form of orifices in the tube.

The coarser the particles left around a perforated tube the more freely does the water enter, but where the sands are

mostly composed of fine grains large orifices would always admit considerable quantities of sand with the water, and even if the tube did not become plugged the water would always be turbid with sand. Consequently, it is sometimes advisable to encircle the perforated tube with a screen which ensures finer orifices than it is possible to drill and hold back at least 80 per cent. of the sand particles. Screens are often made by encircling the drilled tube with perforated brass plates, or even wire gauze through which only very small grains can pass.

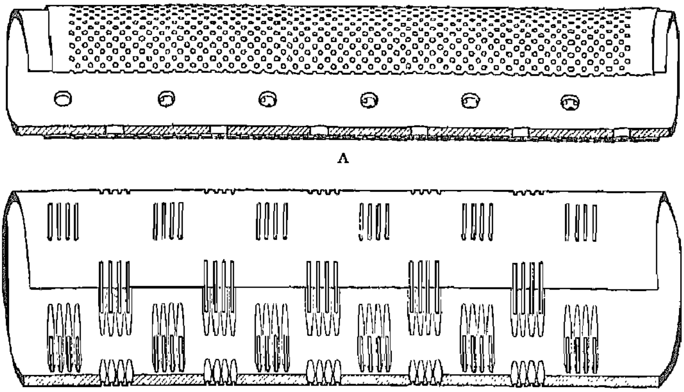
Most makers perforate the points with $\frac{1}{2}$-in. holes at intervals that do not dangerously weaken the tubes, and then solder around a thin brass sheathing with closely-pierced perforations about $\frac{1}{16}$ to $\frac{1}{8}$ in. diameter. The object of a thin plate in preference to a finely-perforated pipe is mainly to produce a large number of small orifices with thin edges, thus avoiding the plugging effect which invariably happens where varied sized grains are drawn into chambers of appreciable lengths. Withdrawn perforated tubes are often found to have their holes almost completely filled by firmly-packed and embedded sand particles that have been drawn thither by the flow of water or forced in during the process of driving. When a plate or fine edge alone has to be passed the possibilities of jambing are much reduced, or nearly avoided, as fragments passing the orifice either sink in the tube or are withdrawn with the water during pumping.

Screening can be accomplished in many simple ways. A fairly effective method is to encircle the perforated tube with a small strand of plaited wire. The junctions of successive coils present irregular surfaces, and consequently spaces which, whilst admitting water and fine sand, retain larger particles and so create a filter. Sometimes in the field drilled points can be rendered effective by hammering on the outside edge of the perforations with a suitable punch, thus forming a contracted entrance such as the perforated plate presented.

Most of these expedients succeed, but as the grains of sand are usually more or less spherical in shape and are consequently more likely to fill and unduly seal a round orifice it is obvious that other shapes would prove more efficient

in practice. Slots would be preferable to circular perforations for avoiding plugging by spherical particles, and are consequently more generally adopted in modern practice for sand screens. These may be placed horizontally or vertically, the former being more usual owing to greater simplicity of manufacture.

Slotted screens are now generally made by winding specially moulded hard brass wire tightly around a perforated pipe. In the process of rolling the wire a fine outside edge is given to the strip which then produces slots with larger



A

B

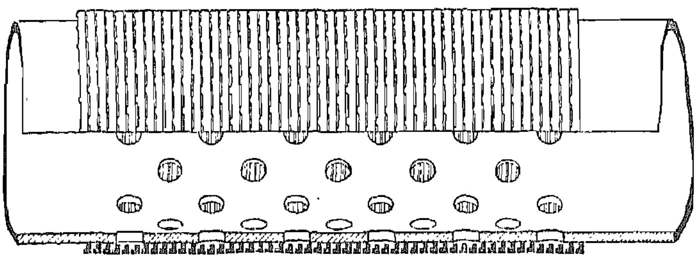
FIG. 12.—Sand screens.

A. Perforated pipe surrounded by perforated brass plate.
B. Milled perforations with smaller outer width.

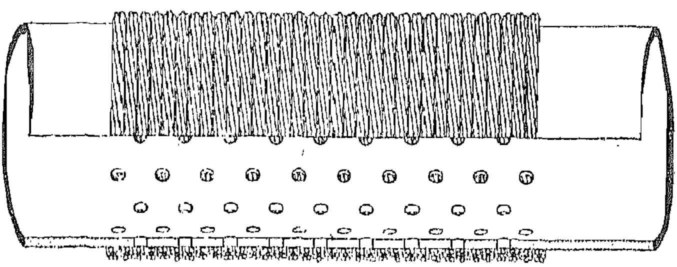
internal width than the external. These screens are illustrated in Figs. 12 and 13.

The main object of water screens is to obstruct the admission of the coarse grains whilst allowing the free entry of the small until a natural packing is produced which when once formed will not be disturbed by a determined maximum rate of pumping. If, however, the rate of extraction of water is increased the accelerated inflow of water will generally influence the sand body for a larger distance around, causing the finer particles again to enter the well until a new equilibrium is established, with the creation of a larger area of infiltration free from the obstructing influence of the finer material.

Once a natural packing has been formed it should be disturbed as little as possible or sand trouble may constantly recur. If the tube well is not deep enough for the pointed piece to escape surface vibration during pumping the surface pump should be firmly fixed to a stout post or otherwise supported. For the same reason the water-level should never be lowered below the sand from which the



A



B

FIG. 13.—Sand screens.

A. Perforated pipe surrounded by shaped wire.
B. Perforated pipe surrounded by wire rope strand.

water is drawn, otherwise the flush of water along the perforations is very liable to upset the natural packing which was formed under water. Channels of flow are thus formed which wash sand into the well. When tube wells work under such conditions much trouble may arise from recurrent entry of sand, but this is not always the case, as sometimes air gains access immediately the level of liquid falls to the top of the perforations and the pump fails to yield more than the quantity rising beyond that point.

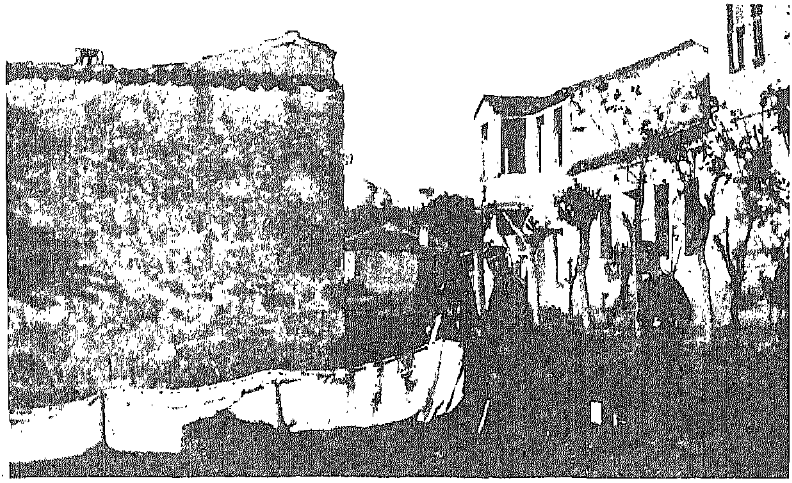


PLATE XXIII.—TUBE WELL SUNK IN STREET AT DEDEAGATCH.
Water led into canvas trough for horse watering.

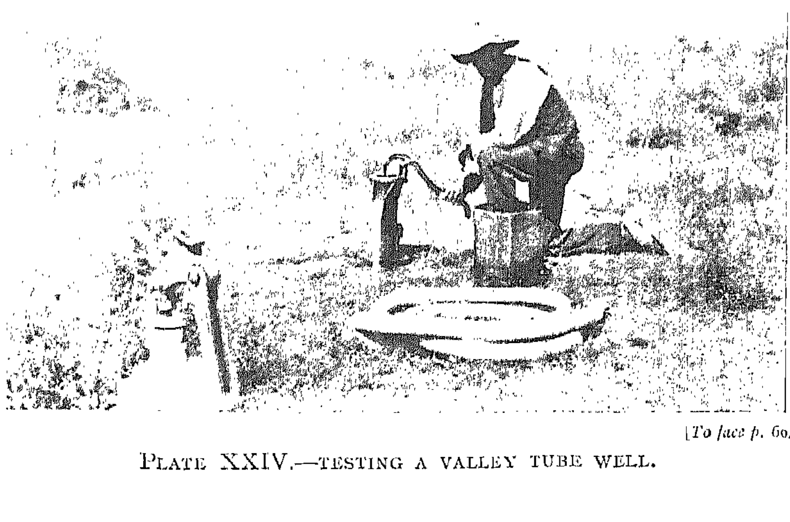


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PLATE XXIV.—TESTING A VALLEY TUBE WELL.

Driving Apparatus.—The most portable and simple arrangement for driving tube wells is that illustrated in Fig. 14. A hollow C.I. monkey slides over a bar, which is supported vertically by the tube to be driven. By means of two ropes passing over pulleys at the top of the bar the drop weight may be alternately raised and allowed to descend by gravity so that it strikes an attached clamp or cap fitted to the upper length of tubing. It is the driving apparatus that practically fixes the length of the tubes, as it is inconvenient to raise the monkey and drive the tubes unsupported if more than 5 ft. out of the ground. A tripod, as illustrated in Fig. 15, is equally suitable but lacks the portability and simplicity of the single pole, whilst possessing few compensating advantages.

Failing a driving apparatus a sledge or mallet may often be used for driving home the tubes if a platform of some kind is made upon which to work, but ill-directed blows usually lead to accidents.

Where the ground is soft and compressible almost any

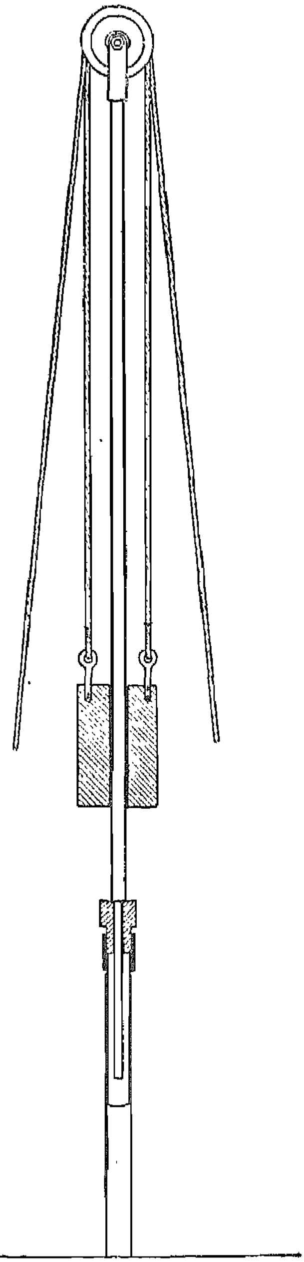


FIG. 14.—Simplest apparatus for driving tube wells.

form of clamp or drive head will suffice, but to penetrate hard sands or indurated clays or boulders exceedingly hard driving is sometimes necessary, and badly designed or

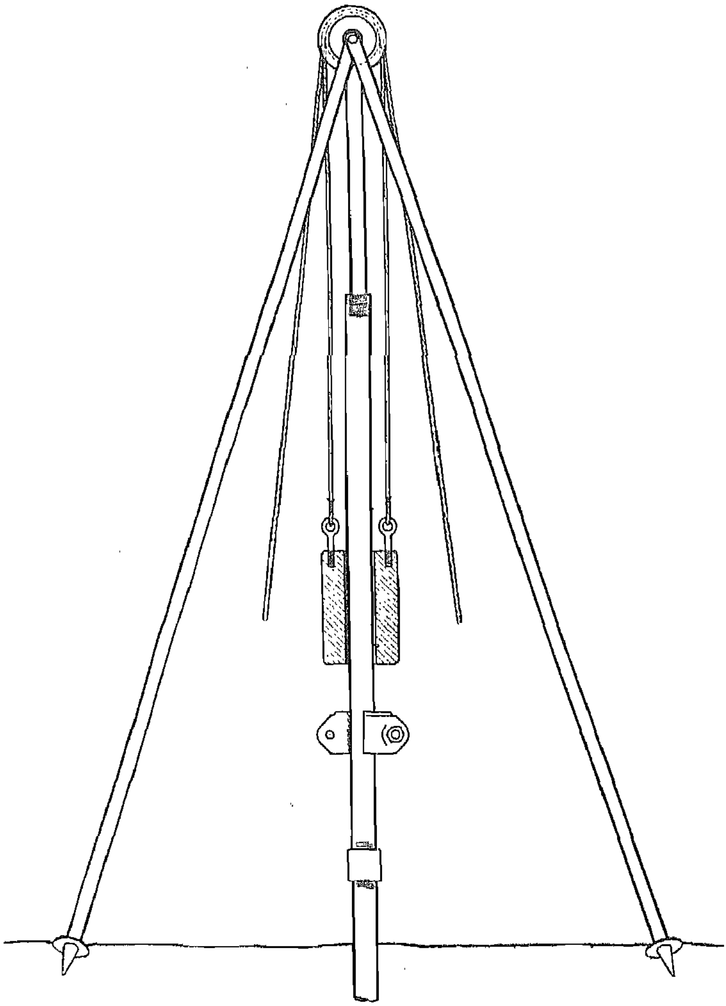


FIG. 15.—Tripod arrangement for driving tube wells.

imperfectly manufactured drive heads or clamps may cause much trouble. A female drive head (Fig. 17, A) that replaces the socket necessitates the removal of the socket each time

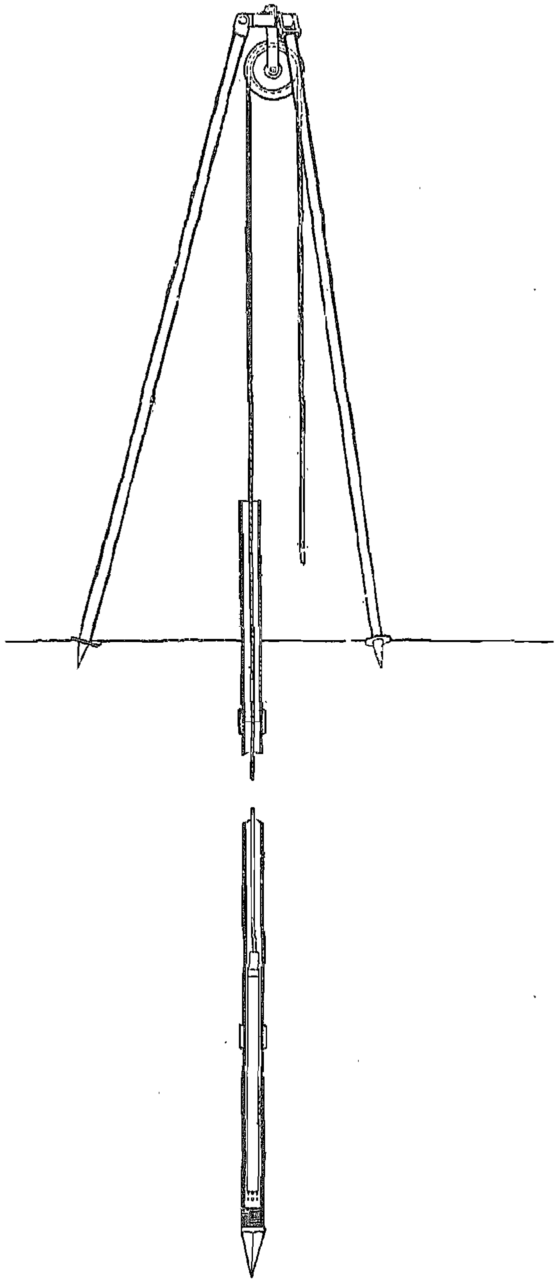
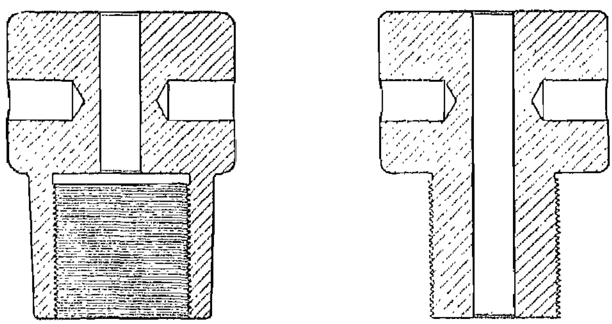


FIG. 16.—Method of driving deep tube wells.

a joint is added and is liable to cause the pipes to break at the base of the threads under heavy blows. Such a misfortune necessitates not only re-screwing the pipe end but also extracting the piece of piping left in the drive cap. A better design is Fig. 17, B, showing a male cap which should be threaded so that it butts on the pipe and transmits a direct blow. In both cases good metal nicely tempered must be used or they become knocked out of shape and squeeze the drive rods which they support.

When a depth of about 50 ft. is reached, or the stratum is too hard to drive further safely owing to the distance of the



A B

FIG. 17.—Two forms of drive heads for tube wells.

blow above the point, an arrangement is sometimes provided for applying the blow at the bottom. In such cases a long steel bar is lowered on a rope and the blow is delivered direct upon the steel point by letting the bar fall after lifting (Fig. 16).

Clamps.—Some operators prefer the use of clamps that firmly grip the pipe and receive the blow of the directed monkey on their upper edge. For heavy driving they are liable to slip, but in some respects they are better than a driving cap if well made. They have the further advantage that the clamps can be so fixed that the blow can be delivered where desired and near the ground if heavy driving is necessary.

Accessories.—The following tools should accompany a 2-in. drive-well outfit:—

Strong box to contain tools.
Set of ½-in. Clearing Tubes, 42 ft.
Monkey, 100 lbs.
Pulley Bar for 2-in. Tubes with 2 Cotton Ropes.
Funnel, 2-in. Gas Connection.
2-in. Tube Clamps.
2-in. by ½-in. Reducer.
2-in. Cap.
2 Chain Levers for 2 in.
1 Bemis and Call Wrench.
1 Stilson Wrench for ½-in. Tubes.
1 set 2-in. Gas Dies and ½-in. do.
1 set 2-in. Gas Tap and ½-in. do.
1 set 3 Wheel Tube Cutters.
10 3-in. Cup Leathers.
10 3-in. Valve Leathers.
1 pair 2-in. Driving Clamps.
6 spare Bolts for do.
1 Spanner for do.
1 File and Handle.
1 tin Paint.
1 1-lb. ball of Waste.
1 Oil Feeder, filled.
1 2-in. Drive Head.
1 Withdrawing Chain and Link.
1 Plumb Bob, Line and Winder.
1 pair Wheels for Pipe Cutter.
1 pair ½-in. Lowering Clamps.

2-in. tube well sets, each comprising:—

1 Abyssinian Drive Point, coated Wire Gauze.
8-5 ft. and 1 2-ft. lengths of 2-in. Steam Tube specially screwed to butt.
1 3-in. Pitcher Spout Pump, War Office pattern, but made with Leather Clack, 2-in. Suction G.M. Valve to Bucket and P.B. Set Screws.

Withdrawing Tube Wells.—A truly-driven tube well can generally be withdrawn without difficulty. If the strata are very soft, a few rotations whilst applying upward force with a wrench or pinch-bar beneath the clamp may suffice to free the tube, but more often some more intensive form of power must be applied. When a tripod is in use the monkey may be lowered under the driving clamps and repeated upward blows administered. Even without a tripod the monkey may similarly be used by hand and the tubes freed, but there is always a danger of the tube fracturing at the base of the threads. If those expedients fail the tubing may be

levered up with heavy timbers pivoted on a fulcrum near the tube itself, as in Fig. 18, the clamp being lowered and the operations repeated as the string is raised.

A more scientific method is to use screw or hydraulic jacks or, preferably, a hollow-spindle jack which encircles the pipe and operates against the clamp. After a few feet have been raised the remainder often comes up by hand, the process being materially assisted by turning the tubes.

If the tube fails to respond to such methods it may be

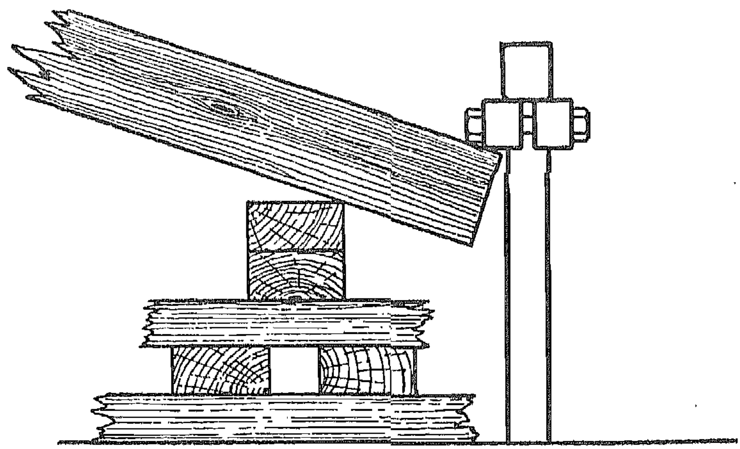


FIG. 18.—Levering up tube after driving.

safely assumed that it is bent, and if its recovery is important the only method is to dig it out.

Process of Driving a Tube Well.—It is essential that the tube should be driven absolutely vertically if much unnecessary work is to be saved and subsequent accidents avoided. Until the first two tubes (10 ft.) are driven home the verticality should be constantly checked by a plumb-line held at arm's length between the observer and the tube at several different angular points of view. If the tube is slightly out of vertical it can generally be pushed into place by pressure exerted on the tubing whilst the blows are being delivered, otherwise the pipe should be withdrawn and started again in a new place. From the author's observation in the field it is evident that few are capable of judging when an

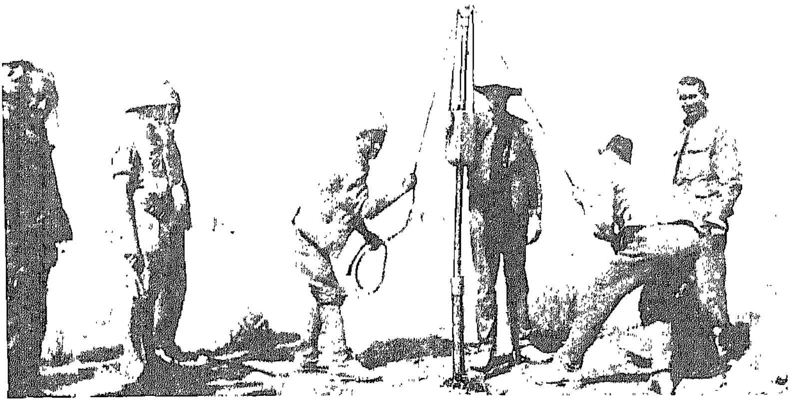


PLATE XXV.—DRIVING A TUBE WELL IN THE VARDAR DELTA, SALONIKA.

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PLATE XXVI.—DRIVING A TUBE WELL AND ENDEAVOURING TO STRAIGHTEN A DEFLECTED TUBE.

object is vertical, especially if there is inclined ground or any irregular object in the vicinity; consequently the plumb-line should always be used.

In soft ground the descent will often be 2 to 3 in. a blow, and 5 minutes a tube is quite a customary rate of progress. A fairly regular stroke should be delivered when the rate of progress will give a fair clue to the nature of the strata being penetrated. The striking of rock or a hard boulder is generally noticed at once by the ring and rebound of the pipe coupled with no penetration. Curvature of the tube is usually indicated by resistance to rotation combined with difficulty of driving.

Progress is often facilitated in compact clays by introducing a little water into the tube or around its exterior. A puddle is thereby produced which will enter the perforated point and relieve the strain by allowing the entry of material that cannot be further compacted. Usually, however, when water has been introduced it is advisable to rotate the piping frequently to avoid the lateral resistance of swelling clays and to produce a lubricated surface against which the piping can slide. It is a good plan to rotate the pipe a fraction of a turn at each blow when in tough ground.

The admission of water in more than small quantities is not to be recommended, as its presence conceals any natural influx of water, and it also neutralises the natural water-head in the penetrated water stratum which might otherwise, unaided, clear the obstructions in the perforations and rise in the tubing.

Sometimes extremely tough clays very nearly compel a suspension of work, dozens of heavy blows failing to drive the tube forward more than an inch. Such compact beds often overlie a sand, and after a foot or two the tube may leap forward again. Bands only a few inches thick caused much trouble to pierce at times in the Macedonian deposits.

Driving in shingle beds or boulder-strewn streams is generally a very tedious operation. The hardened point may split or drive aside some fragments but others may resist the blows and no progress is possible. Under such circumstance the tube should be withdrawn and tried elsewhere, and if one perseveres it is usually possible to hit a

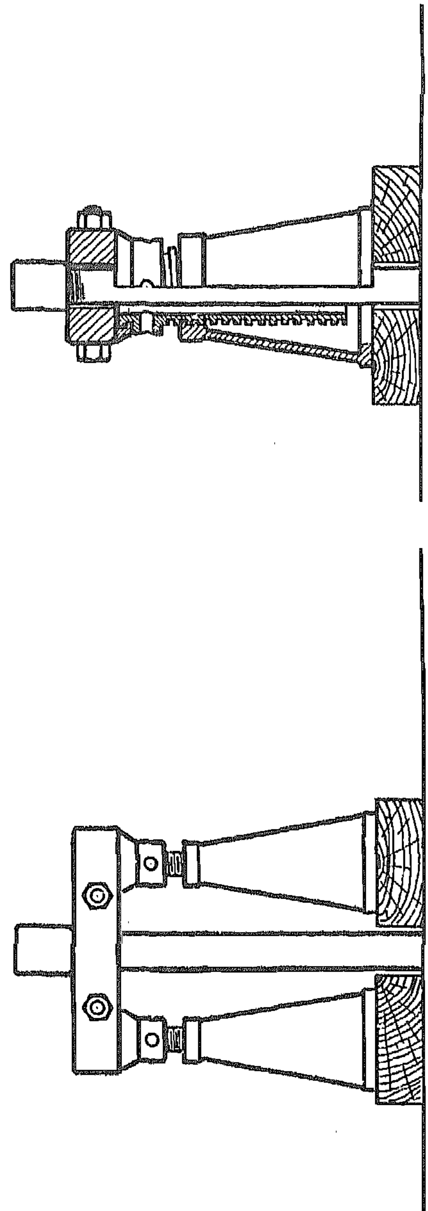

FIG. 19.—Methods of jacking up tubes.

A. Jacking up tubing with ordinary screw jack.
B. Hollow mandrel jack for raising tubing.

spot where boulders can be missed and the desired depth attained. It is not often that one is led to operate in boulder-strewn river-beds but they can be handled. In one case, in Greece, nearly a dozen wells were sunk into a torrent bed near the mountains before success was realised. A feature that developed here, though somewhat unusual, is worth recording. Although a rapid stream was flowing at the surface the tube wells were dry at the depth of a foot or two and continued so until a deep source was penetrated yielding a clear, bright, mineralised water with none of the properties of the surface flow and a static level below that of the stream. The pebble and boulder bed of the river was rendered almost impervious by cementation with a red clay, a disintegration product of the neighbouring limestone mountains. Cases have been observed when instead of a clay cementation the detrital matter of a river course has been practically cemented by carbonate of lime.

It might here be desirable to emphasise the importance of making air-tight joints in tube wells. A faulty joint admitting air is fatal to success, as a moment's suspension of pumping leads to admission of air and causes the pump to lose its water. All joints should be tightly screwed up after careful cleaning, and removal of burrs or bruises, followed by a light painting of mixed red-lead. Where heavy punishment has been administered to the tubing, thereby endangering the tightness of joints, the whole string should be firmly twisted each time the point reaches some resisting material. No pains should be spared in ensuring a perfect joint by cleaning and oiling each threaded end before attachment. If a thread became damaged in the driving the end should be cut off and the pipe rescrewed.

The heavy driving to which the tubes are sometimes subjected renders them highly magnetic and dangerously crystallises the metal. When screwing on a new end after a fracture the crystalline fracture will be observed, and the magnetic properties are manifested by the cuttings of the die standing out like needles from the tube. Repeated use under severe punishment renders the tubing very liable to damage.

When driving in wooded country the striking of large tree roots may absolutely stop progress or force the tube

to one side so that deeper driving is impossible. Some failures in Turkey were ascertained to be due to this cause.

Recognition of Strata and Water.—Successful tube-well work depends upon close observation and correct interpretation of the events that occur during the process of driving. Accurate observation of such details as the rate of descent within a specific period of time or the number and strength of blows administered, the sound of the blow and the resistance to torsion, etc., enable one with practice to formulate a very fair section of the strata penetrated. By plotting the rate of progress per unit of time the work is graphically represented and will show at a glance the relative hardness and thickness of each stratum passed. One such graph is shown with its interpretation in Fig. 29, p. 93.

Often an approximate idea of the formation is known beforehand, thus facilitating an interpretation of the results, but, generally speaking, the following characteristics enable different beds to be recognised :—

Soft Clay.—Easy driving, rapid descent, dead blow without rebound, dull sound, slight but decided and continuous silent resistance to rotation.

Tough Indurated Clay.—Hard driving, little progress, but quite appreciable descent each blow, no resonance, considerable but silent and continuous resistance to torsion, often rebound of monkey.

Sandy Clay.—Intermediate between above.

Fine Sand.—Usually very hard to penetrate dry or wet, fair resistance to torsion, slight gritty sound when rotated, often rebound of monkey with dull resonance.

Coarse Sands.—Usually easily penetrated, and more so when saturated with water, progress often unsteady, irregular distance traversed at each blow, twists easily with very gritty sound, no rebound of monkey.

Gravels.—Easy driving, but irregular descent at each blow, gritty sound on twisting pipe with irregular movements as pebbles are pushed aside. Usually quite free after a few revolutions.

Boulders and Rock.—Little or no progress, rebound of monkey and sometimes pipe, easily rotated unless driven out of plumb. Loud resonance at each blow.

A certain amount of the material being penetrated will often enter the tube through the perforations, and samples can be raised by lowering on a cord a hollow plummet which, if allowed to fall quickly a few times in succession, will cause some of the ground to enter which can be brought to the surface. This test must be applied with discretion, as if the uppermost beds are soft the holes may become plugged at an early stage of driving.

Entry into a water stratum is usually indicated by an *immediately accelerated rate of descent; indeed, the tubes* may often be driven 6 in. at a single blow, but such is not invariably the case. When the sands are fine there may be little or no quickened speed of descent at each blow, and one must often be guided solely by the knowledge that a sand has been penetrated below the natural water-table of the territory being tested. If water rises in the tube the question is settled, and the most suitable depth for completion is determined by the stationary water-level in the tubing or other features. More often, however, in fine sands the entry of water is far from free, and much patience may be needed to induce its entry as is subsequently explained.

On penetrating a suspected sand at a depth below the estimated water-table, driving is stopped and the plumb-bob lowered to ascertain whether water has risen in the tube. If little detritus is found in the tube when the line is lowered to the bottom and the level of water stands well above the perforations and within 15 to 20 ft. from the surface, the pump may be attached and a test made for its yield. On the other hand, if the lower part of the pipe is plugged with fine detrital matter which might exclude the entry of water it is cleared out by one of the following methods :—

A string of ½-in. pipe is lowered in the tubing to the top of the obstruction, clamped in position, and a hand pump attached. Water is then run in between the well tubing and the ½-in. pipe, and the pump put into operation. By steadily lowering the pipe whilst continuing pumping and adding water the sediment is pumped out until the bottom is reached. Any coarse material which the pump will not raise can offer no obstruction to the free entry of water.

Another simpler and quicker method is to insert a string

of ½-in. pipe and then repeatedly raise and sharply lower by hand after the hole has been filled with water. By holding the thumb over the top during the upward movement and removing it during the quick descent the equivalent of a flap valve is produced, and a jet of muddy liquid can be expelled at each downward stroke. A more scientific adaptation is to have a small ball valve on a seating on the lower end of the pipe which opens during quick descent but closes on lifting. A few rapid movements exhaust the water and sediment. When the latter device is used it is an advantage to enlarge the lower pieces of pipe below the ball-valve, as in Fig. 20, and thus induce a greater volume of inflow and a higher velocity in the smaller section.

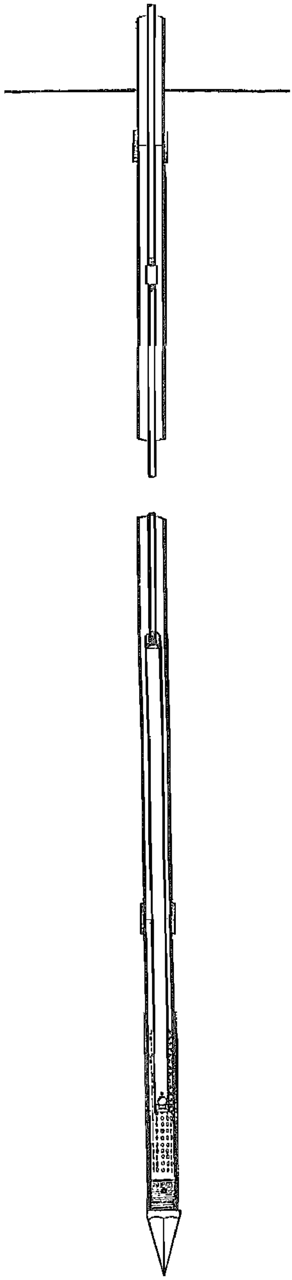

FIG. 20.—Device for cleaning tube wells.

Testing Yields.—Even when the selection of sites has been good, the tube wells accurately driven, and the interpretation of the strata and presence of water correctly diagnosed, successive wells may fail to yield water solely on account of impatience or unscientific pumping. At first sight such a statement appears ridiculous; nevertheless, in dozens of cases failure has been followed by complete success by persistent and intelligent application of the pump where it was difficult to account geologically for the presence of a dry sand below the

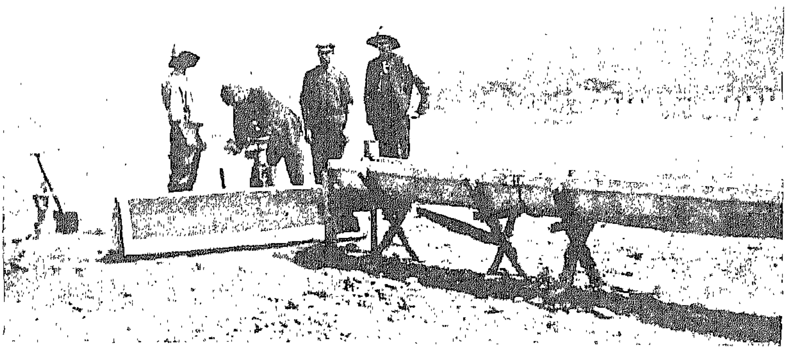

PLATE XXVII.—TUBE WELLS FEEDING WATER TROUGHS ON LARGE FLOOD PLAIN IN SERVIA.

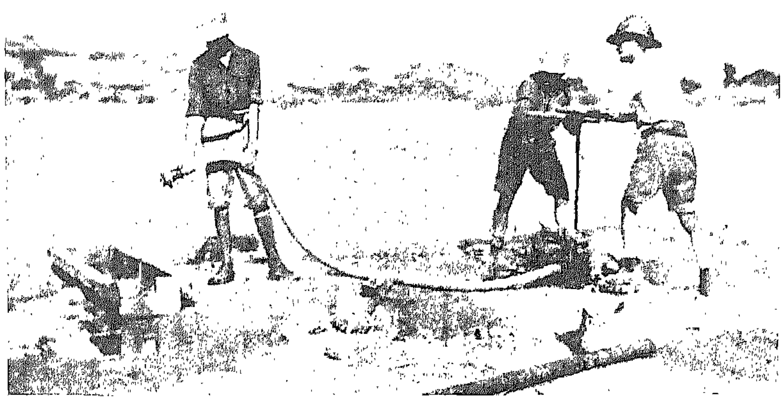

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PLATE XXVIII.—TUBE WELL COUPLED TO REGULATION HAND LIFT AND FORCE PUMP.

known water-table of the district. The above applies even to cases where experienced workmen have failed.

When water is suspected and the tube is clear to the bottom a simple test is to run water into the well, when if in a dry sand it will all run away, but if in a free water sand the level of liquid remains practically stationary or quickly sinks to a fixed level after the in-run is stopped. The quantity of water that can be run into a well is, in fact, an index of the well's pumping capacity, for if the sand-bed is saturated it will yield its contents as freely as it will absorb water. If, therefore, admitted water consistently percolates away even slowly, eventually maintaining a fixed level, there is reason to suspect the existence of a water-bed, and initial failures to secure a yield should not discourage further efforts.

The common pitcher-mouthed kitchen pumps supplied for tube wells are of the suction type, with a lower valve that can be tripped by raising the pump handle high enough to cause a projection on the bucket to strike the hinge side of the suction valve. It is then possible not only to prime the pump but run water into the tubing itself by tripping the lower valve. By alternately applying a heavy suction on the well and tripping the valve to allow the water to rush back a maximum disturbance is created in the well, and if only a tiny inflow of water manifests itself the stratum from which it flows will tend to break down by the repeated pressure and suction to which it is subjected.

Apparently many sands are composed of closely-compacted grains of variable size, and these do not readily disintegrate although saturated with water, but if once the smaller particles which unite and bind together the larger can be put in motion the main body quickly crumbles away. Possibly the driving of a tube is partially responsible for this phenomenon by further consolidating an already closely-packed grouping, but, whatever the reason, there is no doubt about its common occurrence being the cause for frequent failures. Constantly applied pressure and relief which gradually induces the ingress and egress of small quantities of water eventually break down the sand body, and at once there is an inrush of muddy liquid in which fine particles

predominate. A few minutes' continued hard pumping generally causes a continued inrush of sand and water, during which the grains of sand steadily increase in size. It is very important at this stage to maintain a rapid rate of pumping by relays of men or the sand will settle and plug the lower tube if the flow is stopped, thereby, perhaps, necessitating the insertion of cleaning tubes.

Much annoyance may be experienced at this stage by a

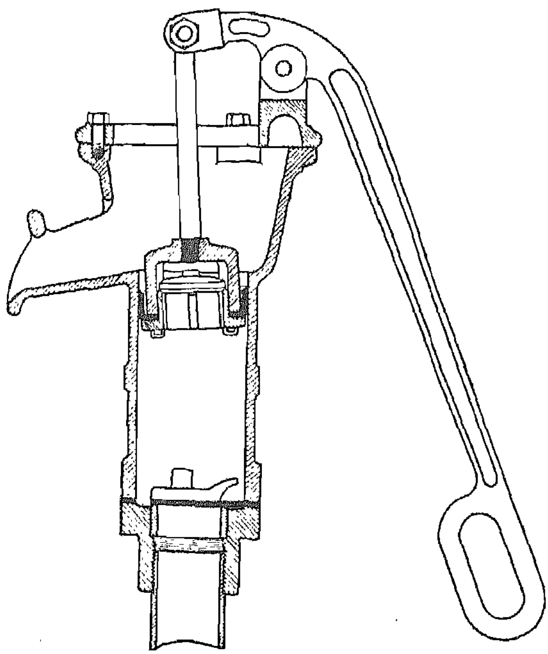

FIG. 21.—Pitcher-mouthed pump used for tube wells.

heavy mass of sand settling on the valve seatings and especially jambing in the bucket-valve guides throwing the pump out of action till cleared. For this very reason it is extremely advisable to employ pumps to which access to the bucket-valve is possible without removing a top-piece. Sand grains of medium size are the most objectionable in this respect, and both before and after the expulsion of this grade which binds the bucket-valve in its guides the process is more simple. Ultimately, after from $\frac{1}{2}$ to 2 hours' pumping

in the case where fairly large perforations are used, particles the size of peas rise with the water which has by then got nearly clear and the well settled to its normal yield.

Under the above-named conditions it is often impossible to bring in a well if the usual fine screen is used. The small orifices become clogged so firmly that they do not admit of the full benefit of the pump action, and they do not allow the sand bodies to break down sufficiently to induce a useful inflow of water. Such sands will only yield large quantities of water when for an appreciable distance around the well all small particles have been abstracted, leaving a residue of coarse material that could not enter the tube but which readily allows the movement of distant infiltrating water towards the perforated point.

Occasionally *fine, regular-graded sands are struck which* yield a water always clouded with fine particles. Each time pumping ceases the suspended sand settles to the bottom and practically plugs the tube. Usually profitable supplies of water are unobtainable from tube wells sunk into such beds, as if fine screens are employed the inflow of water is reduced to useless quantities. It is only occasionally that such fine sands represent all the beds in a vertical sequence of deltaic deposits or river sediments; generally repeated trials at various depths will divulge the occurrence of coarser sand layers, which will more freely yield up their water contents. Often the same lenticle of sand can be tapped a short distance away where the grains are much coarser.

It has been remarked that many of the very fine sands of deltaic or river origin yield highly sulphurous waters, due probably to the undisturbed conditions of sedimentation that encouraged the deposition of vegetable and animal matter. This feature was observed in the Vardar and Galiko deltas and in the Cherna river valley in Servia.

It is obviously difficult to determine from such imperfect data the exact position to leave a tube-well point to secure the maximum yield. Supposing good coarse sand were obtained and the well still failed to give a moderate yield, although the water-level was high, it might be assumed that either the sand-bed was thin or only part of the perforations were inserted in the coarser sand. Often the raising or

lowering of the tubing 1 ft. will cause a very great increase in yield, so the attempt should not be omitted.

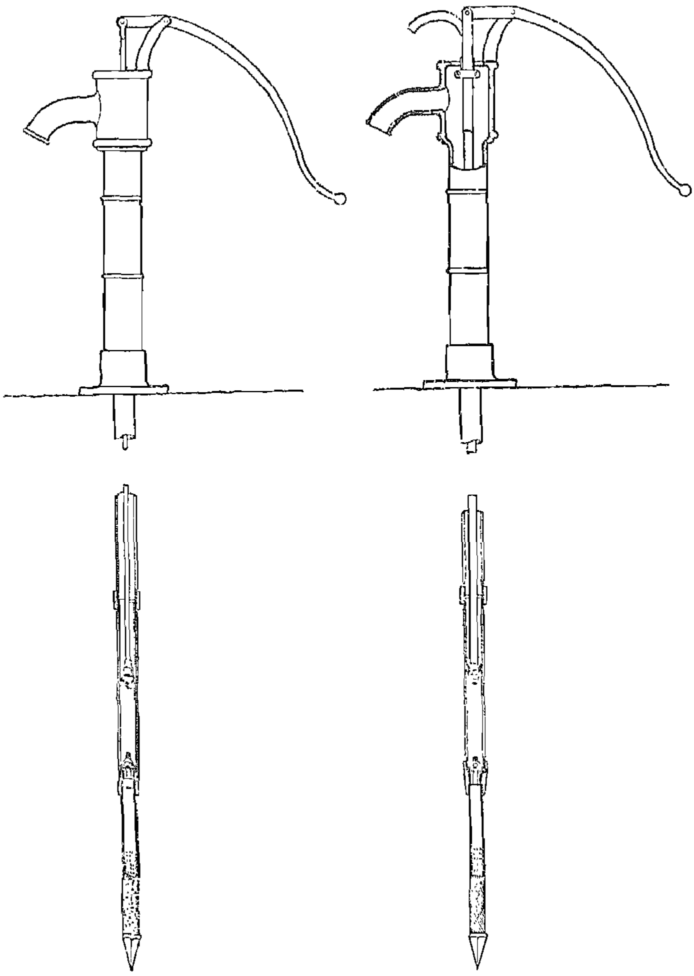

FIG. 22.—Special forms of pumps for tube wells.

A. Use of pump when water-level is low.
B. Type of pump used when much sand present.

Where the water-level does not rise sufficiently high to permit a suction pump being used it is possible in some

cases to sink a shaft sufficiently deep to permit the attachment of a pump barrel within reach of the water. The pump plunger would then be worked by a rod connected with the surface fulcrum handle, as in Fig. 22. Fig. 22 (B) also illustrates a type of pump sometimes used where sand is present with the water, or sand may continue in suspension for a long while. In this pump the plunger is attached to tubing and has reversed cups, and the fluid rises in the tubular rising main on the downward stroke of the plunger. The higher velocity in the contracted rising main ensures the better transport of suspended sand to the surface, and the plunger is less scored by sand.

Selection of Sites for Drive Tube Wells.—Geological knowledge is desirable for the successful location of tube wells, and they should certainly not be sunk haphazard without careful study of the local topography and stratigraphy. Tube wells may commonly be driven in the following situations :—

(*a*) Deltas of large rivers.
(*b*) River valleys, stream-beds, and ancient or modern water-courses.
(*c*) Plains in which rivers meander, or lakes occur.
(*d*) Beaches and dune country.

Only unconsolidated sediments of recent age (geologically speaking) can usually be pierced by tube wells, and it is these modern deposits filling depressions or covering older strata that should be sought. Some idea of the nature of the underground strata may often be forecasted, as they are generally formed by the disintegration of the older beds within the particular drainage area. Their recent age ensures comparative horizontality, although the conditions of deposition often introduce extreme lenticularity and lateral variation.

Deltas of Large Rivers.—These are rarely free from a large development of sandy deposits, although such is not an invariable rule. Clays and sandy-clays may predominate to such an extent that as sources of water supply their value is negligible. Generally, however, extensive deposits of sand, and even gravel, are more or less sporadically deposited in deltas where changeable conditions, currents, climate, movements of land, etc., cause successive deposition of sandy

and clay sediments. The changing courses of rivers cause frequent removal and re-deposition of the same detrital matter, so that a particular bank or lenticle may have changed its position and been resorted many times before reaching its present resting-place Notwithstanding these changes there is usually a succession of sands and clays with innumerable intermediate gradations, all more or less saturated with water below a defined water-table. Sometimes ancient sand- and gravel-beds are now covered by thick deposits of clay alluvium, as in Egypt, which alluvium must be pierced to reach the underlying water deposits.

A failure amidst deltaic conditions where the formations vary so much within short distances should not deter further trials. At times sandy zones traversing a more argillaceous region are revealed by surface evidence, and these should be sought for when disappointments have been experienced or are thought possible. Such sandy belts were easily detected and successfully exploited amidst clayey parts of the Galiko delta at Salonika. In one case where the delta deposits closely hugged rising tertiary strata, and where swift currents were probable during deposition, coarse sands were penetrated by 2-in. tubes at 15 ft. from which the water rose to the surface giving a pumping yield of over 1,000 gallons per hour per tube; only 20 yards away an excavated well sunk in ignorance, in the tertiaries, was dry at 20 ft. Three men could sink these tube wells in 20 minutes. The width of the coarser sands did not exceed 200 ft., and they constituted a strip traversing more compact sediments.

In some deltas considerable quantities of mineral salts have been precipitated with the detrital matter, a condition probably due to concentration of mineralised water or sea invasions in areas isolated and subjected to evaporation by sun and wind. Concentrations of mineral salts often occur where the water-table is sufficiently near the surface for intense evaporation to induce the continual ascent of capillary water, from which dissolved salts are eventually precipitated as saturation is attained. Many salses and bad lands are formed in this way. Such conditions occur in the Lahej delta at Aden, and in parts of the Egyptian delta, but amidst such surroundings repeated trials may bring to light

strips along which an underground circulation is maintained, and consequently sand bodies from which the soluble salts have been leached and carried away to the sea in solution. Endeavours should be made to locate main drainage channels where the flow of water has brought about complete or partial dissolution of salts. Methodical analyses of water may act as a guide in the search for zones of less mineralised water.

River Valleys.—These often present favourable features for drive tube well-work in all countries. Ancient river terraces may frequently be seen fringing the valleys, and in their sand or gravelly nature lies a clue to what may be expected at lower levels below the present line of saturation. When river valleys contract to gorges little or no detrital matter is deposited and the bare rock or beds through which the river has scoured its path are exposed to view. Valleys of medium width which enable floods to pass without great scouring action but, nevertheless, occasion a current strong enough to carry all finely-suspended detrital matter away are nearly always underlain by beds of gravel or sand through which sub-soil water flows quite independently of that above ground. For this reason tube wells driven into such valleys generally tap copious supplies of clear undefiled water quite separated from the surface turbid and polluted streams. If driven sufficiently deep into highly porous strata there is little chance of the upper stream water being drawn in, particularly when fine saturated sediments separate more porous water-yielding deposits.

Valleys of wide expanse with little fall caused by the changing course of slow-running streams may deposit considerable quantities of silt that is useless as a source of water supply, but even here careful examination or methodically-planned tests may disclose sandy zones from which useful supplies of water can be drawn. Such areas may be indicated by sandy surface deposits replacing the more usual clay and loam. Sometimes the difference is manifested by a change of vegetation.

Another valuable clue is to note clearly any sinuosities in defined valley courses, for it is obvious that the greatest scouring action would proceed on the convex edges of streams deflected by hills along a sinuous course. Obviously

in such deductions the present sinuosities of the flowing stream must not be considered too seriously, as its momentary position is merely accidental. The contours of the valley banks which have been the determining factor in main- or flood-stream deflection must alone be used in guiding locations.

River valley sediments have been largely exploited by tube wells in the United States where enormous gravel deposits underlie the extensive flood plains through which the great Continental rivers flow. These valleys yield copious and permanent water supplies with a water-level that rarely falls little below a normal river-level.

During a water investigation in the Island of Antigua, British West Indies, where a large part of the country is composed of igneous material, the author was able to locate a number of gravel-filled valleys where the presence of large volumes of water was a foregone conclusion. These valleys descended to approximately sea-level, and were covered with a heavy alluvium that concealed the underlying gravels and sands which carried away unobserved most of the season's rainfall. The sea formed an effective barrier against the loss of water, and the area of the valleys assured the existence of sufficient storage to carry over all likely dry periods. In some of the valleys stretching from the mountains flowing tube wells would certainly be struck.

In an impounding scheme intended for irrigation purposes on the Langhaza plain, near Salonika, excavations showed this feature of scouring in a most startling, and, in this case, very disturbing way. On the convex side of a sharp curve in a ravine about 100 ft. across, the gravels reached a depth of 30 ft., and the section was as shown in Fig. 23.

The quantity of water passing this point in the dry season was 40,000 gallons per hour, and tube wells sunk into the deeper section of the bed would have yielded nearly this amount, whilst wells sunk to one side would have proved unproductive during the dry season.

When an uneven bed is suspected through the existence of a rocky base, and the presence of water is considered likely beneath dry river courses, it is possible to survey the whole width by tube wells, when the deeply-scoured portions

PLATE XXIX.—PUMPING INSTALLATION AT GALIKO.
2,000 gallons per hour obtained from two 2-in. tube wells in river course, replaced the larger infiltration chamber seen on left of photo.

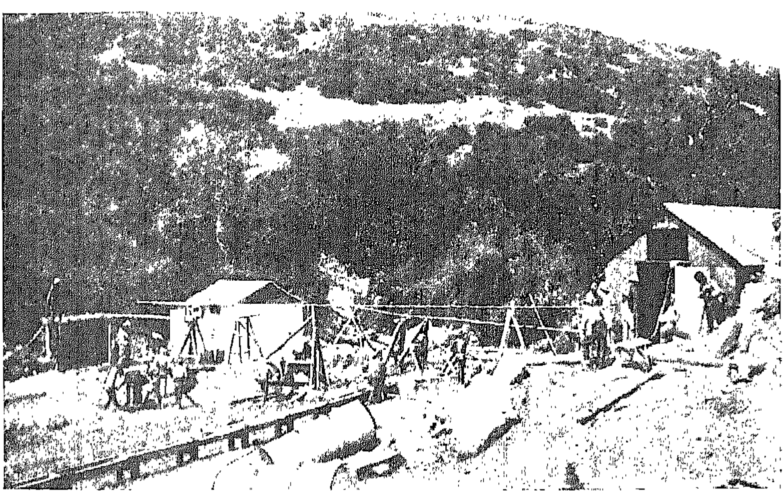

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PLATE XXX.—ERECTING PUMPS FOR PUMPING WATER FROM SPRING TO CAMPS SEVERAL MILES AWAY.

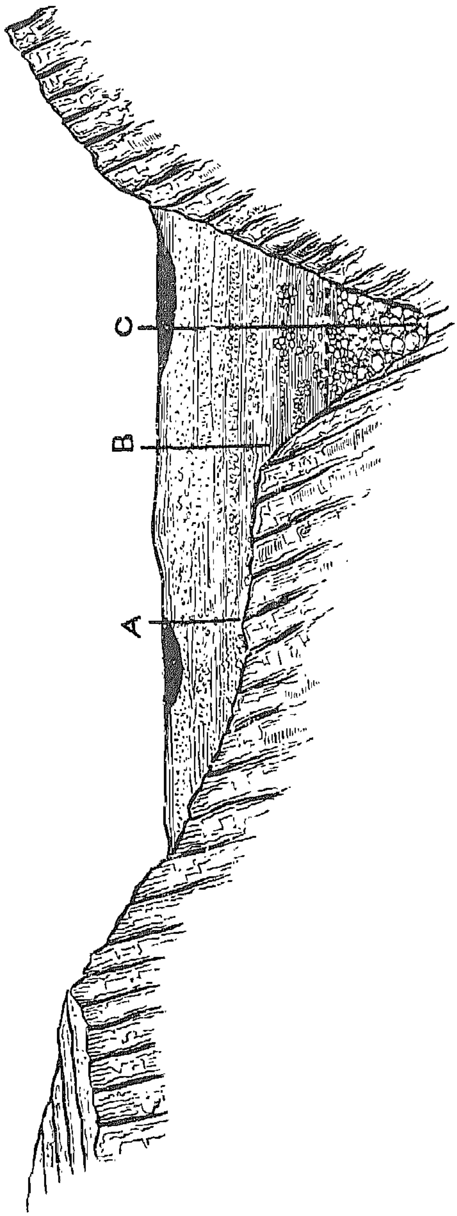

FIG. 23.—Section of water-course at Langavuk. In rainy season water flowed at A and C, and at times filled the whole valley. During the dry season useful supplies of water were only obtained at C.
This section illustrates clearly how important a methodical exploration of a dry river course may be where water is urgently required during the midst of a dry season where the water-level is very low.

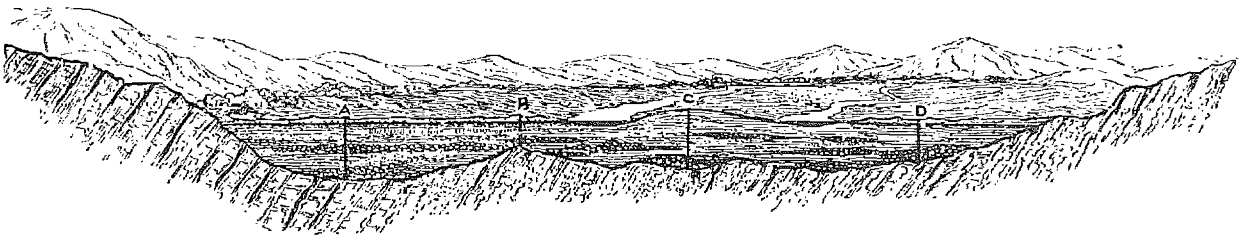

FIG. 24.—*Section of* wide dry river course surveyed by tube wells. Good yields were obtained at the lowest points where coarse sands prevailed.

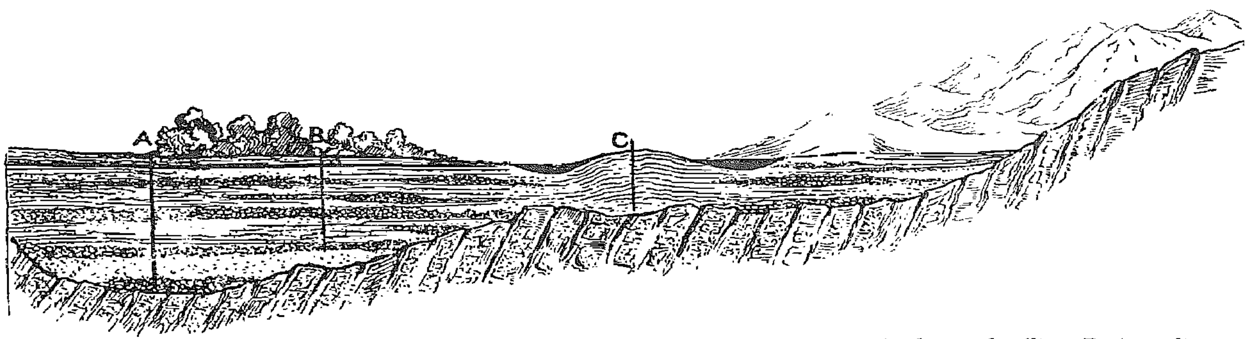

FIG. 25.—Section of river course explored by tube wells. At C no water was obtained, as only silts. Best results were obtained to left, far removed from the modern river course and now covered by agricultural land.

will be revealed and the spots ascertained where water is likely to flow even at the driest part of the year. Fig. 24 shows such a channel so examined.

One example of the importance of such surveys may be illustrated. A military division on the Struma was largely dependent for water upon some shafts sunk on the banks of a stream running into the Struma valley. During the dry season these failed, and shafts sunk in the river-bed itself were difficult, costly, their yield small and capricious, and they took time. Tube wells and men were hastily despatched, and within six hours of arrival several successful wells had been sunk by prospecting the stream-bed. Within twenty-four hours of arrival an abundance of water that never failed subsequently was available from coarse sands at several places across the bed. Their positions are diagrammatically illustrated in Fig. 24. A feature worth emphasising is that the deep sections so located often contain coarser and cleaner sands or gravel than elsewhere where less current prevailed.

In another case considerable quantities of water were hastily required to accommodate the movements of several divisions of infantry. A point where a dry river course narrowed was selected as the only spot where copious supplies were likely to be obtainable at short notice. This spot fortunately, but naturally, corresponded with the point where the water-course was bridged, and where the troops would pass. Within six hours three tube wells were sunk to bed rock and coupled to a Merryweather pump that discharged freely 4,000 gallons per hour. The conditions are illustrated in Fig. 4, p. 36. A wide valley of detrital matter occurred above the selected point where the river course contracted to a width of about 100 ft. in passing a rocky barrier.

Such examples could be multiplied, but they illustrate the importance of intelligent application of simple geological prognostication in the pursuit of water.

One case is perhaps worthy of record as indicating the enormous saving that specialised technical knowledge may effect. The French Army engineers were much concerned about water at a certain base hospital, where reliance was

placed on a large, heavily-timbered infiltration chamber sunk alongside the course of an important river which flowed only during rains. The supply was always turbid through suspension of fine sand; the tank required frequent clearing of in-running sediment, and the supply failed almost entirely in the dry season. On appeal for assistance to the British R.E.'s it was determined to try tube wells, and in a space of 40 minutes two 2-in. wells had been driven with a joint yield exceeding 2,500 gallons per hour. These were coupled to the suction of the power-driven pump by flexible hose, and not only was a regular yield of 2,000 gallons per hour maintained but the water was quite clear and pure, consequently saving constant pump repairs, storage for settlement, and the repeated costly cleaning. In driving one of the wells the writer was much perplexed by the great difficulty in driving after a certain depth. It was eventually discovered that the tube had struck an ancient revetment used to protect the banks on the wash side of the stream, the tube point consequently being deflected to the angle of the slopes (see Plate XXIX).

Considerable lateral variation of the sediments must be anticipated in river deposits, and a single failure must not be regarded as condemning the prospects of tapping a copious water source in a river valley. At times several unsuccessful wells in succession have been driven before a coarse sand or gravel was struck in perhaps a more depressed point or a deeper erosion channel in the bed. Having once satisfied oneself that a considerable quantity of water must pass along a certain drainage channel, efforts should not be relaxed until very exhausted trials have ended in failure. If the drainage area is such as to make it certain that water traverses the course, and no surface flow is in evidence, it is perfectly clear that there is a free-running water channel somewhere in the bed.

As exemplifying the surprises of such work a case in Servia is worth recalling. A village near the Cherna, behind the main-line defences, was practically without water except the distant filthy river which had traversed the Bulgar lines. Through the village passed a small gulley in which there were certain sandy sediments, but although appealed

to these appeared to offer so little prospects in the absence of any indication of water that the success of a tube well appeared hopeless. Nevertheless, it was decided to make a trial. At a depth of 17 ft. a yield of 500 gallons per hour was obtained in coarse sand after passing some very hard uppe· beds. The peasants and locally-camped troops were using the water within 1½ hours of our arrival at the village.

Water-courses are often crossed by dykes or masses of rocks over which the water is forced to rise to the surface and pass after a long subterranean flow in deep-seated gravels or sands. Points above such obstructions are very favourable locations for tube wells, and have been successfully developed for important supplies.

One such locality, where for a long distance above the spot no surface water was observable and below no water was ever again seen, was developed at Karudere.

A note of warning should be sounded concerning the productive life of tube wells in river courses of insignificant drainage areas with a considerable gradient. The passage of water in comparatively fine sands along highly-sinuous courses may be checked for a long period after rains, but prolonged spells of drought cause a lowering of the water-table until tube wells become inoperative. This happened in one case where, before installing a somewhat important pumping base for a Greek Division some weeks after the successful driving of the wells, a further trial was decided upon solely on account of the observed gradient and extension into the dry season. The test failed and the reduced temperature of the pipes proved that air was being drawn into the service. On disconnecting the piping it was found that the water-level was depressed below the upper perforations of the tube wells, representing a fall of 4 ft. within a few weeks.

An Italian unit in the Monastir district had for weeks been very hard pressed for potable water at a locality where the metamorphics predominated. In the space of 30 minutes a well was driven to below the upper bad waters into valley sediments, yielding at a depth of 13 ft. 700 gallons per hour of first-class water.

Plains.—Plains into which water enters or along which streams meander or lakes form, introduce some highly interesting problems when considered from a water supply point of view. Those flanked by mountain ranges receive large volumes of water in wet seasons, and, indeed, incessantly if springs are prevalent or snow perennial. Even elevated plateaux with low rain-falls have often a high water-table. Unfortunately such plains are often composed largely of clay or fine sandy clay sediments which are incapable of yielding water fast enough to supply tube wells, although in most cases large shafts collect by slow percolation sufficient for normal peasant requirements.

The problem, though complex, yielded interesting results in Macedonia during the war. Great plains like the Struma, Langaza, Vardar, Bralo, and Monastir have been successfully exploited by tube wells. Although in all these plains clays predominate, sandy areas corresponding to old river courses have been located, and in suitable situations, with reference to the local water-table or other features, successful tube wells have been driven. Sometimes in the height of the dry season sandy courses, even when discovered, have been entirely pierced to the underlying clays without reaching water, although the sands were still damp, but the same sandy bed might prove productive of water at a lower level if its direction could be traced.

Close study of the surrounding hills will often afford a clue to the general direction in which large ravines or main valleys discharge their sub-soil drainage into the plain; indeed, a talus will often mark the locality. It will be readily understood that former variations of climate, as well as of level caused by denudation, capture of one stream by another, etc., could easily have caused more pronounced water channels than those in evidence to-day, and if the talus area is visible it is often possible to deduce the extent and course of ancient water channels carved out of the valley alluvia that generally prevail. Many such were located in the Macedonian plains, and where fed by perennial springs or melting snows large yields of water resulted, although beyond a restricted strip nothing but impervious clays were penetrated. In cases where the catchment

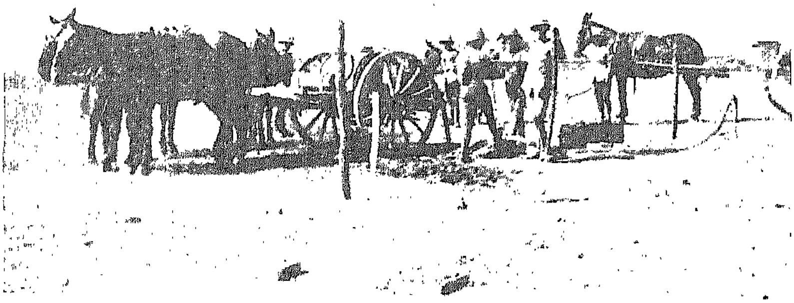

PLATE XXXI.—ARMY WATER CARTS BEING FILLED FROM TUBE WELL.
(Section of this site, Plate XXVII.)

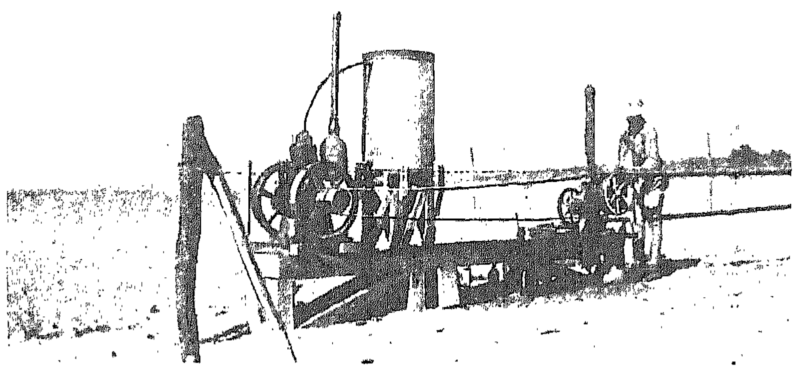

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PLATE XXXII.—TUBE WELL FITTED WITH OIL ENGINE AND PUMP FOR PUMPING WATER TO DISTANT CAMP.

It will be seen how little there was to guide the selection of a site.
(Section of this site, Plate XXVII.)

area was inconsiderable and the available supply of water known to be very small it was, of course, useless to drive wells except when the water-table of the plain, often approximately lake-level, lay within 15 or 20 ft. from the surface. Sandy zones were in some cases pursued by successive abortive efforts until the water-table was reached. At the higher levels the sands were penetrated to their base or to the fixed maximum depth, and their capacity for containing water was ascertained by its immediate loss when introduced. Under such conditions it was a foregone conclusion that water would be obtained if similar strata could be found at an elevation which was not above the water-table of the plain. Where water was urgently required in one area no less than six wells were driven before a sandy zone at the correct level was struck. A succession of wells then yielded all the water required for a brigade in a very waterless region at the driest period of the year.

Fig. 26 and Plates XXXI and XXXII show the conditions of such deposits.

Quite frequently the course of an extinct river-bed is at present indicated not by a depression but by a rise (talus) due to accumulation of detrital matter conveyed during storms of insufficient duration or intensity to carry it away and carve out a channel.

In some plains with gentle gradient the water-table is close to the surface, and drainage by canals is often necessary to facilitate the drying of the land. Some tube wells on the Langaza plain gave natural artesian flows from coarse sands only 28 ft. deep covered by a light layer of loamy material. The hydrostatic head in winter was a foot or more above the surface, but towards the end of the dry season it fell to a foot or two below the surface. Extensive areas were located where tube wells could thus be sunk in an extraordinarily brief space of time, and groups were coupled capable of jointly yielding 10,000 gallons per hour for an Army agricultural farm.

Lakes.—The comparative quiescence of lake waters tends to encourage a settlement of fine silt and clay or material unsuitable for yielding supplies of water, but such is not

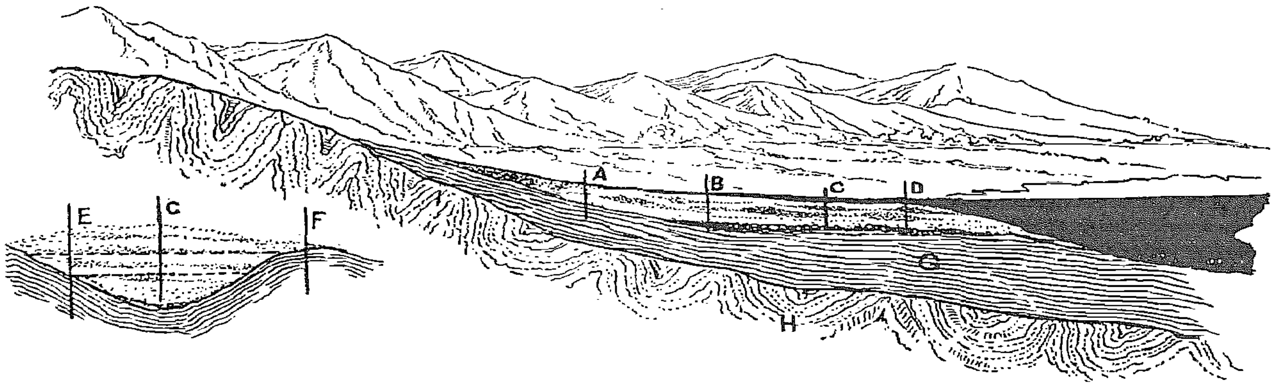

FIG. 26.—Section of valley sediments showing geological conditions where a water-productive sandy channel, A, B, C, D, was traced by tube wells amidst clay sediments, G, overlying ancient distorted rocks, H. The section on left shows how abortive wells proved the limits of the sandy channel. The water-level was determined by the level of the lake on the right.

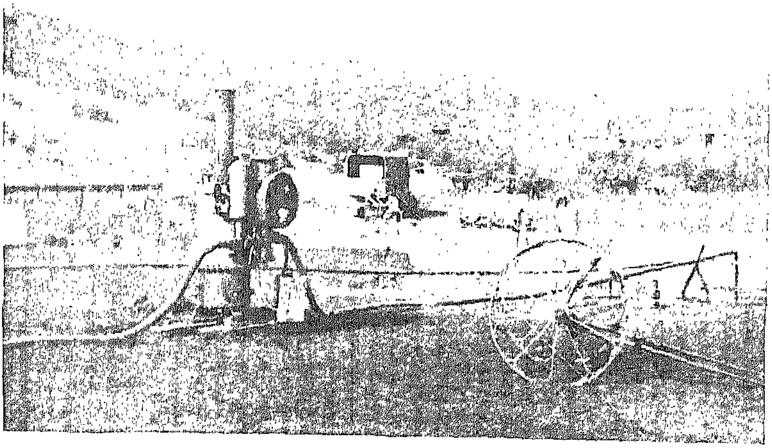

PLATE XXXIII.—PUMPING FROM TUBE WELLS.
Mereweather steam pump fed by two 2-in. tube wells yield 4,000 gallons per hour.

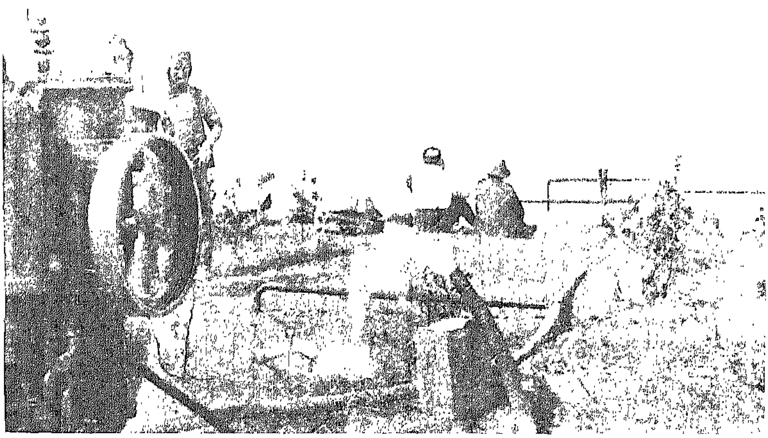

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PLATE XXXIV.—PUMPING FROM GROUPED TUBE WELLS.
Mereweather fire pump fed by group of coupled tube wells on shores of Lake Dorian yield 3,000 gallons per hour.

always the case. There is, in addition, often a contemporaneous deposition of vegetable and animal matter whose decomposition transmits to contained stagnant waters objectionable, if not injurious, properties. Consequently, even if sands are penetrated sufficiently below the present lake bottom to avoid contamination of deep-seated water with that of the lake, they often display the above-described qualities which militate against their employment. Experience in Macedonia showed such waters generally contained malodorous sulphuretted hydrogen which was quickly evolved on exposure to the air, leaving no disagreeable taste.

Along the low-lying edges of lakes in rocky areas there is often a beach zone of variable width in which shelly or sandy deposits attain quite a considerable thickness and extent, and these are often very prolific sources of good water less disposed to organic contamination than those in the lake. Numerous tube wells have been sunk under such conditions with every success, as is shown in Plate XXXIV of wells on Lake Doiran. One group of wells at Doiran railhead was completed in a few hours during the rapid advance into Bulgaria, and yielded 3,000 gallons per hour when grouped and connected with a Merryweather steam pump. For the convenience of moving troops and labour battalions working on the roads, many tube wells were sunk around the lake during the advance into Bulgaria.

As in the case of plains it is often possible to secure better and purer supplies of water where there are streams flowing into or out of the lake. Such positions are unfavourable for the accumulation or sedimentation of organic material, the sands may there be coarser and deeper; and there is a better circulation of underground waters to disperse objectionable matter resulting from stagnation. Very successful tube wells were sunk into the main outflow channel of Lake Doiran, and Plate XXXIII shows an inflow into the same lake. In the latter case where springs oozed up the water-level rose above the surface of the ground, and a yield of 3,000 gallons per hour was obtained from two $1\frac{1}{2}$-in. coupled tube wells.

Beaches and Coastal Dune Country.—Such selected places often yield considerable quantities of water. The sand

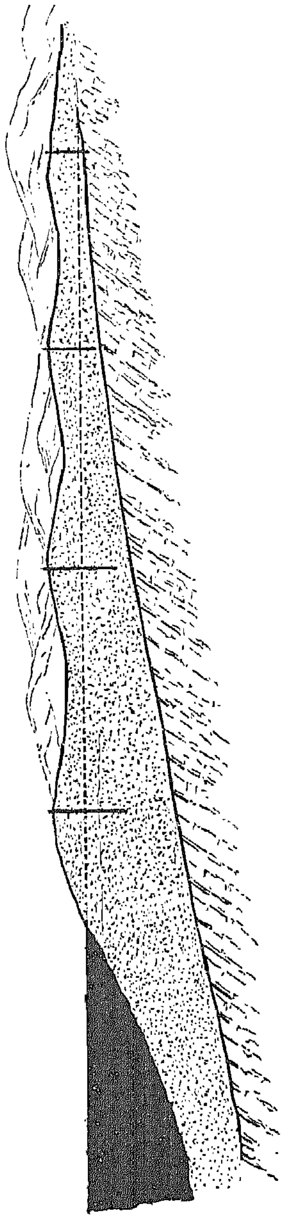

FIG. 27.—Beach sands and gravel deposits as reservoirs for water.

Sand deposits with shell-beds and coarse seams often fringe the coast and yield substantial supplies of water little contaminated with salt water. Tube wells may often be successfully sunk in such beds as occurred at Gallipoli and along the Palestine littoral.

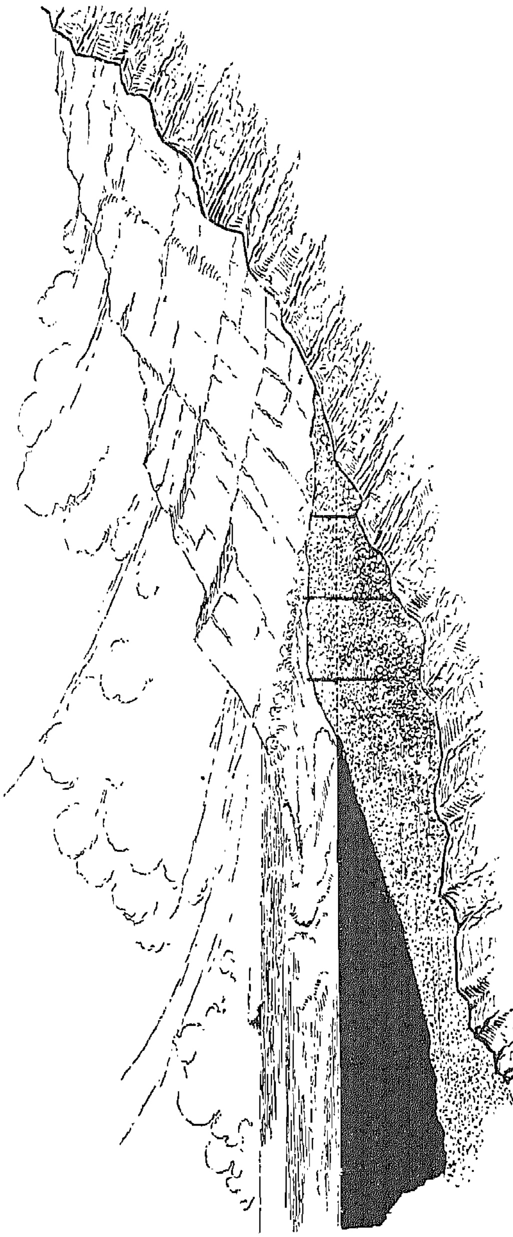

FIG. 28.—Beach deposits as fresh-water containers.
Under these conditions beach deposits at Anzac, Gallipoli, yielded supplies of water.

deposits fringing a sea-shore may cover a large area, and below sea-level become saturated with fresh water migrating from the land. Water derived from such sands is often slightly brackish, and may be too salt for potable purposes, but, commonly, the brackishness does not prevent its use by troops or residents. Tube wells can readily be sunk in such ground where the elevation does not incur a depth of more than 15 to 20 ft. to reach sea-level. They may often be driven within a few yards of high-tide line without suffering much in quality unless too heavily drawn upon. Occasionally they may be sunk far out to sea.

During the Gallipoli campaign limited quantities of water were obtained from the beach sands at Anzac, even where a very narrow margin separated the hills from the beach, and at Helles supplies were similarly obtained where nullahs cut a channel into the cliffs. Along the Sinai and Palestine coast-line tube wells were successfully driven in the dune country. In the landing at Dedeagatch a whole division was supplied with water from tube wells, some within 300 ft. of the sea, within six hours of landing. A location had previously been selected from ordinary topographical maps without any knowledge of the geological conditions. At Stavros, Salonika area, successful wells were driven within 100 ft. of the sea in a silted-up bay into which a small stream emptied itself close to the foot hills some few hundred feet distant.

Grouping of Tube Wells.—A group of tube wells is generally far more successful than a single well of larger diameter. In extremely coarse sands with a high static level as much as 3,000 gallons per hour have been drawn from a single 2-in. tube well, but this is unusual, and in most cases infinitely better results can be achieved by driving a succession of wells obliquely across the supposed direction of flow. One important advantage accrues from the fact that the local water-level is not so heavily depressed; consequently, diminishing the chances of drawing in air and disturbing the grouping of the sand grains which have ensured a continuance of sand-free water.

The union of two wells to a common suction would naturally be effected by placing the pump at a point inter-

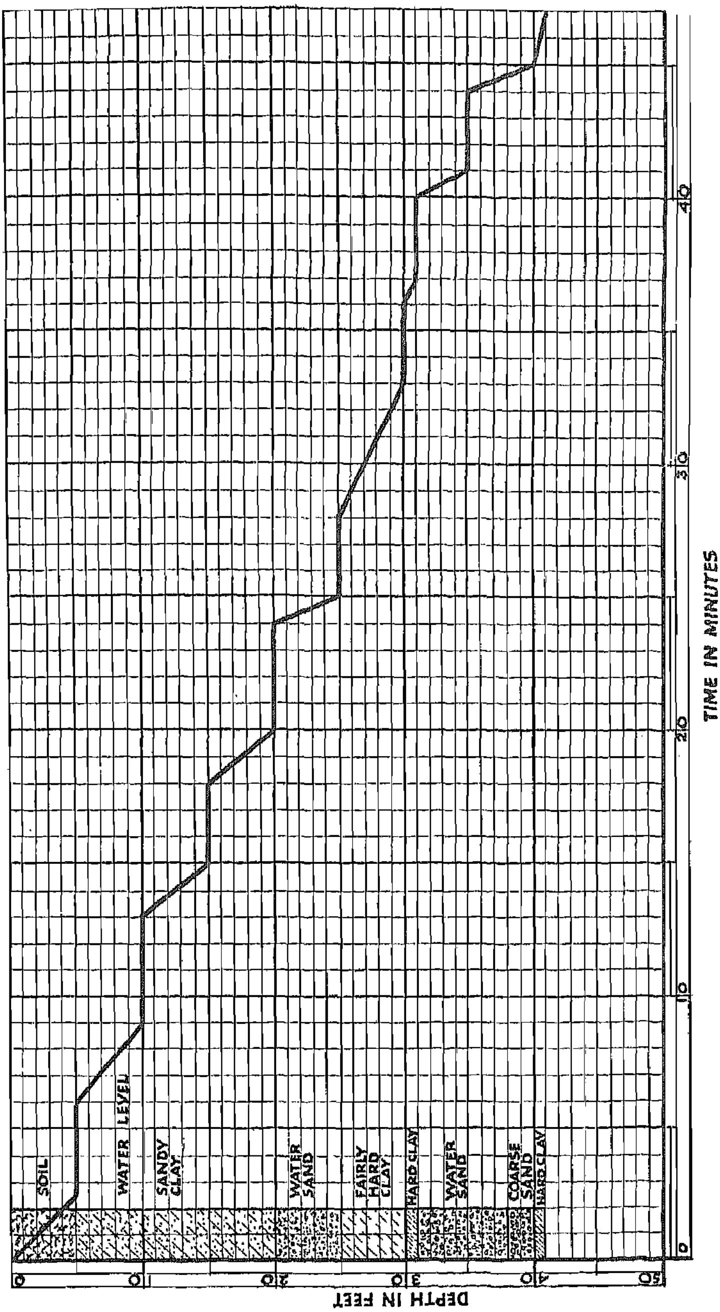

FIG. 29.—Diagrammatic representation of tube-well work. Horizontal lines indicate time taken to attach new lengths of tubing.

mediate between the two, thus equalising the suction action, but the coupling of a number requires more consideration to ensure as much as possible an equal suction at all wells. With a water-level near the surface there are usually no difficulties in group pumping, but with a level of 15 to 20 ft. from the surface much trouble may be found in starting the pump. These troubles arise from the difficulty of disentangling air from separate bodies of water in a horizontal pipe service. Relief can often be afforded by introducing at each well a valve which is only partially opened until the air has been sucked away. The valves also permit the service being primed by filling with water from a point near the pump. In any case, a non-return valve should be interposed near each well to keep the service primed after once being put in operation. A useful expedient in such cases where often the type of pump does not admit of a short high-speed run, such as helps to draw away the air, is to have each tube fitted with a ball valve just above its point. The pressure in the pipes on standing then ensures a tight fit that restricts leakage of water if air gains admission to the service. It is possible to ascertain if all the wells are working by noting the temperature of the pipes at the various wells; those through which water is passing have a different temperature to those containing air, except in the rare cases of the air and water temperatures being identical. By placing a rod or walking-stick between the pipe and the ear it is usually possible to detect clearly the sound of flowing water in those pipes through which it is passing.

Failure to start a group service may always be attributed to the influence of air, and remedies must be sought to effect its removal and, if possible, its future non-admission if the installation is run intermittently. Plate XXXV shows some tube wells grouped for collective pumping.

In one case priming was automatic, as the water always flowed into the pump when pumping ceased. For quick service during movement of troops, groups of wells can be conveniently coupled up to Merryweather fire pumps, when yields of 3,000 to 5,000 gallons per hour can often be made available within a few hours of instructions.

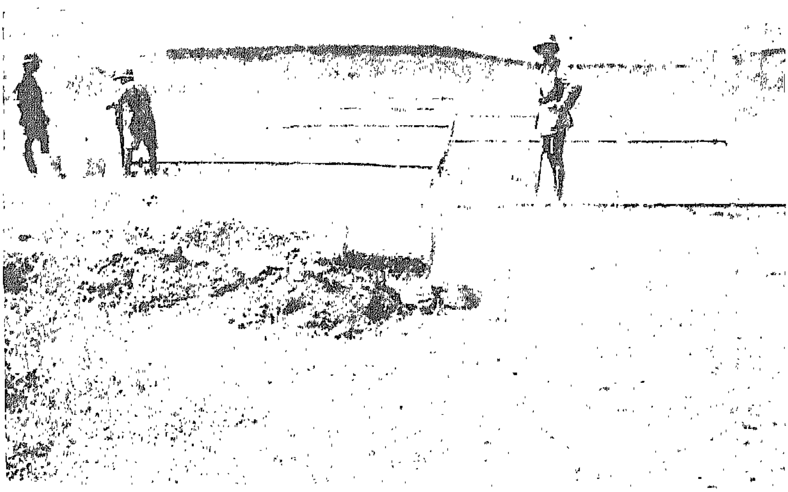

PLATE XXXV.—COUPLED TUBE WELLS.
A group of coupled tube wells arranged for a larger pumping installation.

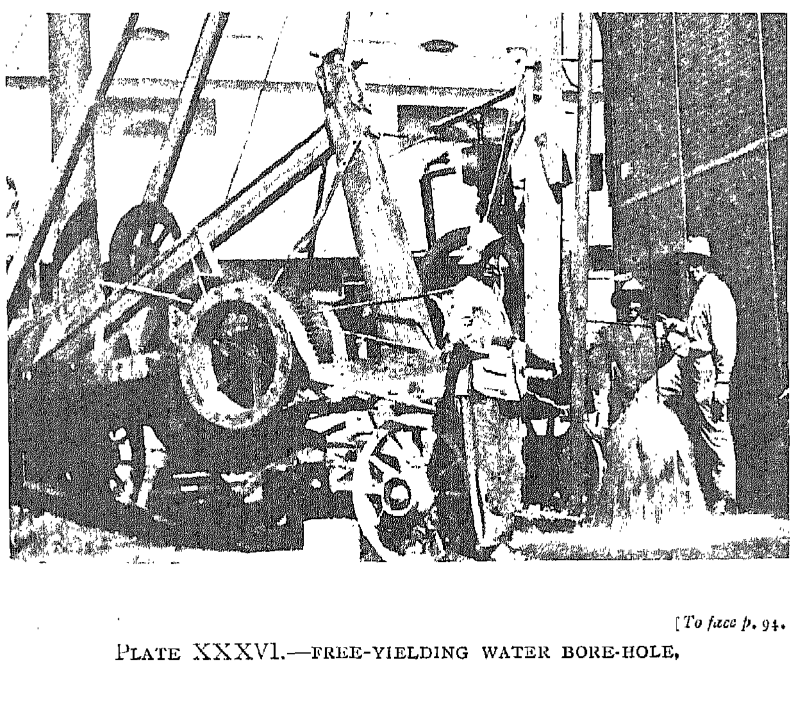

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PLATE XXXVI.—FREE-YIELDING WATER BORE-HOLE.

Purity of Sub-soil River Waters.—Much controversy has arisen as to the purity of waters obtained from underground flows in river courses. There are certainly many cases when the water is simply the normal water where the level is temporarily depressed below the surface, but in most cases it is possible to pass upper layers and penetrate lower waters entirely isolated from the upper whose static level may actually exceed that of the upper.

Considering the worst case first, the dangers appear far less than is often inferred. Even if the river is mainly fed by springs and seepages which traverse the surface and not by subterranean springs—which latter is often the case owing to the river-beds being at a lower level than the surrounding country—the passage of such water along many miles of sandy sediments cannot fail to have had a highly purifying action. Nature is, in fact, only performing what engineers enact by elaborate works for the purification of water, namely, filter-beds. Certainly the filter-beds are not subject to periodical cleaning such as city services prescribe, but even the value of this cleansing is contested by modern scientists, their clarification being an enforced measure to check the decreasing capacity although *adversely* affecting their biological efficiency. It is consequently submitted that waters which have passed long distances underground should not necessarily be subjected to suspicion merely because they are of shallow origin. Even in the event of a spate surface pollution is practically all carried away by the flush of water and does not pass into the ground. Storms which cause a heavy flow of surface water for a brief period may hardly damp sands a few feet from the surface, as has frequently been observed in Macedonia.

That the underground waters of river courses are often quite dissociated from the surface flows of the vicinity is clearly indicated by the following frequent differences in the character of the supply :—

(*a*) Static level of water.
(*b*) Temperature of water.
(*c*) Turbidity of water.
(*d*) Mineral contents.
(*e*) Bacteriological contents.

Both the static levels and the temperatures are often strikingly different when comparing the river and sub-soil waters, proving thereby total isolation from each other. Sometimes the static water-level exceeds that of the surface water-level by one or more feet, at other times it is several feet below. In a mountain torrent at Bralo (Greece) a clear mineralised water was struck in one case at 7 ft. with a static level 4 ft. below that of the flowing stream. Temperatures of sub-soil waters are usually lower in summer and higher in winter than surface flows.

Tube-well waters are generally crystal clear after a few hours' pumping to remove the fine sandy sediment which is at first drawn in with the coarse.

Not infrequently sub soil waters only a few feet below the river bottom possess quite distinct mineral properties. The waters may be hard through longer contact with calcareous sediments or be charged with small quantities of sulphates and chlorides which give them a very distinct mineral water flavour. Highly sulphurous waters have been struck in a number of river tube wells, and even carbonated waters were found in a Cherna valley well.

At one general hospital the water from a tube well, always suspected for no other reason than its moderate depth, was eventually pronounced absolutely free from objectionable impurities, and henceforth drunk unchlorinated.

Record of Results.—Below are given in tabular form the results of tube-well work on the Salonika front, where wells were driven under all kinds of conditions over an area of some thousands of square miles of Macedonia. In order to give the data additional value, interesting details calling for comment are in some cases added.

Diagram, Fig. 30, shows a useful way of graphically representing the work for quick reference, as well as giving the monthly tube-well footage in convenient form.

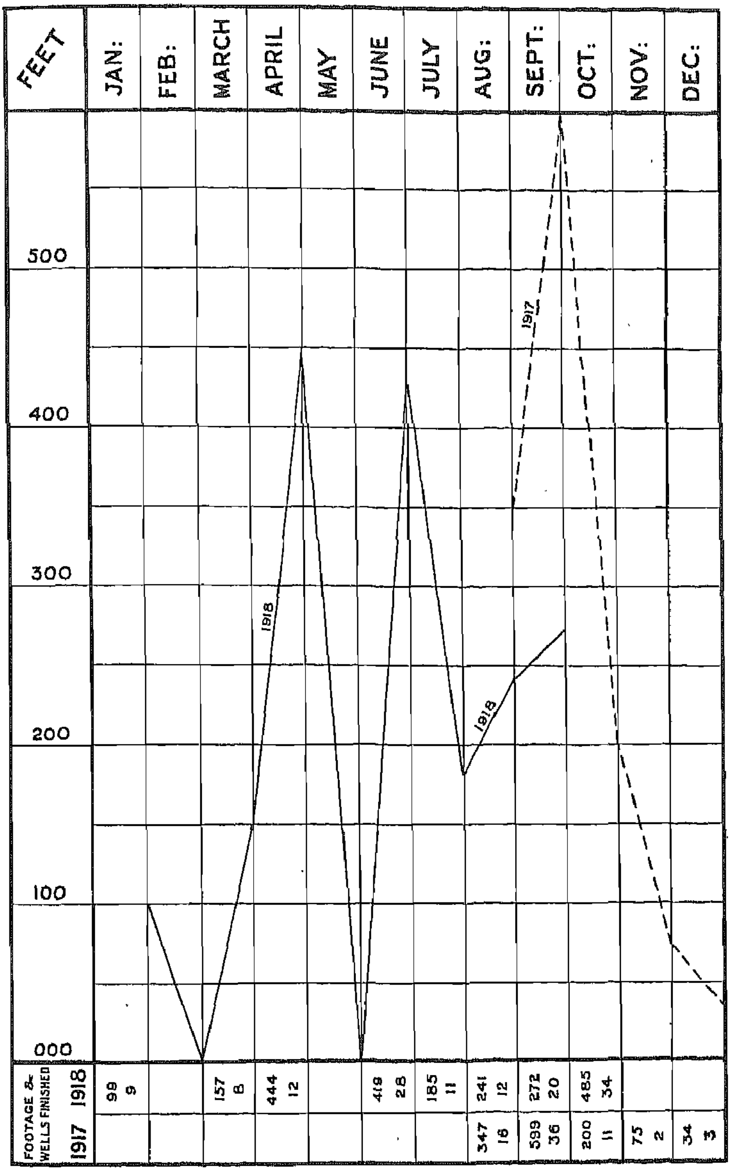

Fig. 30.—Tube-well footage in Macedonia.

MACEDONIAN DRIVE TUBE WELLS, 1917–1918.

Well No.	Date.	Location.	Tube. Size.	Tube. Depth.	Time. Hours.	Capacity. Gals. per hour.	Water-level. Feet below surface.	Remarks.
	1917		inches	feet				
1	Aug. 2	Arakli A.S.C. farm	1¼	28	1	500	1	Langaza Plain.
2	Aug. 10	" "	2	28	1	1,200	1	" "
3	Aug. 10	do. Prisoners' Camp	1¼	30	1	500	2	" "
4	Aug. 11	do. Staff Billets	1¼	28	1½	300	4	Langaza Plain; very hard compact sand that never gave great yield.
5	Aug. 20	Arapli 41st General Hospital	1¼	27	1¼	500	?	Galiko Valley.
6	Aug. 21	Arapli Franco-Servian Hospital	2	14	1¼	1,200	2	Galiko River bed (dry); two coupled to one suction. Yield 2,000 gals. per hour.
7	Aug. 21	Arapli Franco-Servian Hospital	2	14	1¼	1,200	2	Same as above.
8	Aug. 25	Arapli Franco-Servian Hospital	1¼	37	1½	600	?	Galiko Valley. Upper sands too fine to give good yield. Much difficulty in inducing initial entry of water.
9	Aug. 27	Dzumamah (Struma Defences)	1¼	13	1	200	—	Driven across bed of Kopaci stream, now dry; difference of yield due to variable grade of sands.
10	Aug. 27	" "	1¼	15	1	425	—	
11	Aug. 27	" "	2	15	1	260	—	
12	Aug. 28	" "	2	15	1	360	—	
13	Aug. 28	" "	2	18	1	425	—	
14	Aug. 29	Arapli 41st General Hospital	1¼	27	1½	500	—	Very cold water.
15	Aug. 31	Topsin Railway Station (French)	1¼	20	2	nil	—	Too hard to drive further in consolidated gravels and sands.

16	Aug. 31	Topsin Rly. Station (French)	2	18	$\frac{3}{4}$	400	6	On Vardar Valley.
17	Sept. 1	" "	$1\frac{1}{4}$	20	$\frac{3}{4}$	200	6	Sands very fine and equal graded.
18	Sept. 1	" "	$1\frac{1}{4}$	10	$\frac{1}{2}$	400	6	When driven to 15 ft. no water below.
19	Sept. 2	Naresh-Monastir Road Junction	$1\frac{1}{4}$	10	$\frac{1}{3}$	500	1	Edge of Galiko Delta.
20	Sept. 6	Naresh Road	$1\frac{1}{4}$	26	1	500	?	Extremely hard band at 15 ft.
21	Sept. 7	Arapli (Serbian farm)	2	20	1	600	—	Galiko Valley.
22	Sept. 26	Vertikop Hospitals (Franco-Serbian)	$1\frac{1}{4}$	21	1	250	1	On large plain below Vodena. Coupled to main pumping station for feeding *large* hospital centre.
23	Sept. 26	Vertikop Hospitals (Franco-Serbian)	2	21	1	400	flow	
24	Sept. 26	Vertikop Hospitals (Franco-Serbian)	2	25	1	450	flow	
25	Sept. 26	Vertikop Hospitals (Franco-Serbian)	2	23	1	500	flow	
26	Oct. 3	Bralo (Greece) Rest Camp	$1\frac{1}{4}$	7	$\frac{1}{2}$	300	4	In bed of flowing mountain stream in plain 1,000 ft. above sea. Water mineralised.
27	Oct. 3	" "	2	12	$\frac{3}{4}$	300	4	
28	Oct. 14	Itca (Greece) Police Camp	$1\frac{1}{4}$	18	$1\frac{1}{2}$	nil	—	All in very hard clays which *could not be pierced further*. In valley below Delphi.
29	Oct. 14	" "	2	10	1	nil	—	
30	Oct. 15	" "	$1\frac{1}{4}$	8	$\frac{3}{4}$	nil	—	
31	Oct. 15	Itca Rest Camp	$1\frac{1}{4}$	26	1	nil	—	Rock reached after clay.
32	Oct. 16	" "	2	28	$1\frac{1}{2}$	nil	—	Only clays, no sand.
33	Oct. 17	" "	2	25	1	240	15	Coarse calcareous sand; coupled to common suction for power pump.
34	Oct. 18	" "	$1\frac{1}{4}$	23	1	360	16	
35	Oct. 22	Itca stream bed	2	33	2	nil	—	Hard clay after dry gravels.
36	?	Bralo M.T. Co.	$1\frac{1}{4}$	?	?	400	flow	Flow from sands beneath clays on flanks of mountains near Gravia.

MACEDONIAN DRIVE TUBE WELLS, 1917–1918—*continued.*

Well No.	Date.	Location.	Tube.		Time. Hours.	Capacity. Gals. per hour.	Water-level. Feet below surface.	Remarks.
			Size.	Depth.				
	1917		inches	feet				
37	Nov. 27	Main Ammunition Dump, Dudular	2	38	$1\frac{1}{2}$	400	6	Coupled to common suction of power pump. Second well had screen and suffered in consequence; all in Galiko Delta.
38	Nov. 27	Main Ammunition Dump, Dudular	$1\frac{1}{4}$	37	$1\frac{1}{2}$	280	6	
39	Dec. 3	Dudular Ordnance soap waters	2	10	$\frac{1}{2}$	1,000	surface	
40	Dec. 3	Dudular Ordnance soap waters	2	14	$\frac{1}{2}$	500	surface	
41	Dec. 3	Dudular Ordnance soap waters	2	10	$\frac{1}{2}$	300	surface	
	1918							Galiko Plain.
42	Jan. 3	Dudular Ordnance soap waters	2	14	$\frac{1}{2}$	1,000	surface	Galiko Valley edge; in stray sand, coupled to common 4-in. suction 300 yds. from pumps, yet yielded jointly 4,000 to 5,000 gallons per hour.
43	Jan. 3	Dudular Ordnance soap waters	2	14	$\frac{1}{2}$	1,000	surface	
44	Jan. 3	Dudular Ordnance soap waters	2	14	$\frac{1}{2}$	1,000	surface	
45	Jan. 3	Dudular Ordnance soap waters	2	14	$\frac{1}{2}$	1,000	surface	
46	Jan. 3	Dudular Ordnance soap waters	2	14	$\frac{1}{2}$	1,000	surface	
47	Jan. 3	Dudular Ordnance soap waters	2	14	$\frac{1}{2}$	1,000	surface	

48	Jan. 8	Akbunar Nullah bed	2	5	¼	1,000	surface	Sunk to secure yield in silted-up gulley. All tubes driven to bed-rock and coupled to power pump on bank.
49	Jan. 8	,, ,,	2	5	¼	1,000	surface	
50	Jan. 10	,, ,,	2	5	¼	1,000	surface	
51	Mar. 1	Arakli A.S.C. farm	3	29	?	900	?	Coupled to one power pump.
52	Mar. 1	,, ,,	3	29	?	900	?	
53	Mar. 1	,, ,,	3	29	?	900	?	
54	Mar. 15	Monastir-Naresh Road	2	14	—	1,000	surface	Galiko Valley reserve supply.
55	Mar. 16	,, ,, O.D.	2	14	—	1,000	surface	
56	Mar. 16	,, ,, ,,	2	14	—	1,000	surface	
57	Mar. 16	,, ,, ,,	2	14	—	1,000	surface	
58	Mar. 16	,, ,, ,,	2	14	—	1,000	surface	
59	April 1	Arakli A.S.C. farm	3	24	—	8,000	—	In Langaza Plain, pump coupled to Merryweather pump gave 8,000 gals. per hour.
60	April 1	,, ,,	3	24	—		—	
61	April 1	,, ,,	3	24	—		—	
62	April 1	,, ,,	3	24	—		—	
63	April 1	,, ,,	3	24	—		—	
64	April 1	,, ,,	3	24	—		—	
65	April 1	,, ,,	3	24	—	10,000	—	Langaza Plain; group coupled to Merryweather pump gave *10,000 gals. per hour.* The 36-ft. well had coarser sand.
66	April 1	,, ,,	3	24	—		—	
67	April 1	,, ,,	3	36	—		—	
68	April 1	,, ,,	3	23	—		—	
69	April 1	,, ,,	3	24	—		—	
70	April 1	,, ,,	3	24	—		—	
71	June ?	Savakli Railway Station	2	25	?	300	?	Galiko Valley.
72	June ?	Gugunci River bed	2	19	?	1,100	—	
73	June ?	Isiklar Greek Div.	2	15	?	500	5	Upper reaches of Nullah fed by small springs and drainage of medium area. Wells driven on wide, flat, open sands. By end of July water-level had fallen to 9 ft., and they could not be grouped for pumping.
74	June ?	,, ,,	2	15	?	500	5	
75	June ?	,, ,,	2	15	?	500	5	
76	June ?	,, ,,	2	15	?	500	5	
77	June ?	,, ,,	2	15	?	500	5	
78	June ?	,, ,,	2	15	?	500	5	
79	June ?	,, ,,	2	15	?	700	5	
80	June ?	,, ,,	2	15	?	700	5	

MACEDONIAN DRIVE TUBE WELLS, 1918—*continued.*

Well No.	Date.	Location.	Tube. Size.	Tube. Depth.	Time. Hours.	Capacity. Gals. per hour.	Water-level. Feet below surface.	Remarks.
	1918		inches	feet				
81	June ?	Galiko Valley ($31\frac{1}{2}$ K.)	2	15	$\frac{3}{4}$	700	5	Driven in Galiko bed of stream on sand-bank for horse watering. By Aug. 31 level had fallen to 9 ft.
82	June ?	,, ,, ,,	2	15	$\frac{3}{4}$	700	5	
83	June ?	,, ,, ,,	2	15	$\frac{3}{4}$	700	5	
84	June ?	,, ,, ,,	2	15	$\frac{3}{4}$	700	5	
85	June ?	,, ,, ,,	2	15	$\frac{3}{4}$	700	5	
86	June ?	Dudular Railway Station	2	16	—	700	5	The group of wells sunk within an area of about 300 by 300 ft. in the Galiko Delta illustrates the variation of the nature of the sands met with within very short distances. All were driven to equal depths in *horizontal* sediments. The sands were usually fine, thus accounting for comparatively small yields.
87	June ?	,, ,,	2	15	—	500	5	
88	June ?	,, ,,	2	15	—	500	5	
89	June ?	,, ,,	2	15	—	300	5	
90	June ?	,, ,,	2	15	—	100	5	
91	June ?	,, ,,	2	15	—	300	5	
92	June ?	,, ,,	2	15	—	400	5	
93	June ?	,, ,,	2	15	—	400	5	
94	June ?	,, ,,	2	15	—	500	5	
95	June ?	,, ,,	2	15	—	570	5	
96	June ?	,, ,,	2	15	—	400	5	
97	June ?	,, ,,	2	15	—	600	5	
98	June ?	,, ,,	2	15	—	900	5	
99	June ?	,, ,,	2	15	—	500	5	
100	June ?	,, ,,	2	15	—	500	5	
101	July 17	Corsica (26th Div.)	$1\frac{1}{4}$	14	1	700	9	Sand channel in stiff clays. Water-levels on Aug. 31 were 12, 8, and 8 ft. Tube coupled to power pump.
102	July 17	,, ,,	$1\frac{1}{4}$	12	1	700	7	
103	July 18	,, ,,	$1\frac{1}{4}$	12	1	700	7	

104	July 18	Karudere (water-course)	2	14	$1\frac{1}{2}$	600	?	Much sand.
105	July 24	Vardino (Vardar defences)	$1\frac{1}{4}$	27	$\frac{1}{2}$	500	7	Fine dark sand, water sulphurous; sunk in Vardar Valley.
106	July 28	,, ,, ,,	$1\frac{1}{4}$	15	1	nil	—	Too hard to proceed.
107	July 28	,, ,, ,,	$1\frac{1}{4}$	7	1	nil	—	Too hard to proceed.
108	July 28	,, ,, ,,	$1\frac{1}{4}$	15	1	nil	—	Too hard to proceed.
109	July 29	,, ,, ,,	$1\frac{1}{4}$	25	1	nil	—	Too hard at base to go deeper.
110	Aug. 4	Hirsova (22nd Div.)	2	11	$\frac{1}{2}$	1,000	2	Sunk in water-course leading away outflow of Lake Doiran, coupled to 1,500 g.h. power-driven pump.
111	Aug. 4	,, ,,	2	10	$\frac{1}{2}$	1,000	2	
112	Aug. 8	Galiko Prisoners of War Camp	2	38	$1\frac{1}{2}$	500	7	Black sand and sulphur water.
113	Aug. 9	Galiko Prisoners of War Camp	$1\frac{1}{4}$	12	$\frac{1}{2}$	600	7	White sand; clear water.
114	Aug. 10	Galiko Prisoners of War Camp	$1\frac{1}{4}$	20	$\frac{1}{2}$	500	7	Dark sand (Galiko Delta).
115	Aug. 16	Karudere (water-course)	2	18	$1\frac{1}{2}$	800	9	Amidst boulders and gravels. On Sept. 6 water-level fallen 2 ft. more.
116	Aug. 17	,, ,, ,,	2	19	$1\frac{1}{2}$	720	10	
117	Aug. 25	Naresh Road (27 K.)	$1\frac{1}{2}$	28	$1\frac{1}{2}$	small	7	Black fine sand.
118	Aug. 26	,, ,, ,,	$1\frac{1}{2}$	35	2	small	9	Black fine sand.
119	Aug. 27	,, ,, (29 K.)	$1\frac{1}{2}$	28	$1\frac{1}{2}$	nil	—	Good sands in river course, but quite dry at this season.
120	Aug. 30	Salmanli	2	11	$\frac{1}{2}$	700	1	Galiko Valley. Point driven into clay.
121	,,		2	11	$\frac{1}{2}$	700	1	Galiko Valley. Point driven into clay.
122	Sept. 5	Naresh Road ($37\frac{1}{2}$ K.)	$1\frac{1}{8}$	18	1	900	$7\frac{1}{2}$	Coarse sands pierced.
123	Sept. 8	,, ,, ,,	$1\frac{1}{8}$	16	1	900	$7\frac{1}{2}$	Galiko River bed.

MACEDONIAN DRIVE TUBE WELLS, 1918—*continued.*

Well No.	Date.	Location.	Tube. Size.	Tube. Depth.	Time. Hours.	Capacity. Gals. per hour.	Water-level. Feet below surface.	Remarks.
	1918		inches	feet				
124	Sept. 9	Naresh Road ($29\frac{1}{2}$ K.)	$1\frac{1}{2}$	24	$\frac{1}{2}$	nil	—	Soft sands in river-bed but now quite dry.
125	Sept. 9	,, ,, ,,	$1\frac{1}{2}$	13	$\frac{1}{2}$	nil	—	
126	Sept. 14	Karudere river course	$1\frac{1}{2}$	$5\frac{1}{2}$	$\frac{1}{2}$	1,000	$\frac{1}{2}$	All driven to rocky base where rock crossed dry river course. Coupled to Merry-weather pump, yielded 4,000 gals. per hour. Intended for training camps.
127	Sept. 14	,, ,, ,,	$1\frac{1}{8}$	8	$\frac{1}{2}$	1,000	$\frac{1}{2}$	
128	Sept. 14	,, ,, ,,	$1\frac{1}{2}$	$8\frac{1}{2}$	$\frac{1}{2}$	1,000	$\frac{1}{2}$	
129	Sept. 15	,, ,, ,,	$1\frac{1}{2}$	12	$\frac{1}{2}$	1,000	$\frac{1}{2}$	
130	Sept. 17	Karudere Station	$1\frac{1}{2}$	10	$\frac{1}{2}$	1,000	9	Sunk at contracted point of dry river course, coupled to a Merryweather pump. Yield exceeded 4,000 gals. per hour for watering troops in transit. All driven to rock.
131	Sept. 17	,, ,,	$1\frac{1}{2}$	13	$\frac{1}{2}$	1,000	9	
132	Sept. 17	,, ,,	$1\frac{1}{2}$	16	$\frac{1}{2}$	1,000	9	
133	Sept. 17	,, ,,	$1\frac{1}{2}$	21	$\frac{3}{4}$	1,000	9	
134	Sept. 27	Doiran Railhead	$1\frac{1}{2}$	18	$\frac{1}{2}$	750	1	On lake side 1 ft. to 3 ft. above lake-level. Fine sands full of mica flakes, slight sulphur odour. Coupled to Merryweather pump. Yielded 3,600 gals. per hour.
135	Sept. 27	,, ,,	$1\frac{1}{2}$	13	$\frac{1}{2}$	750	2	
136	Sept. 28	,, ,,	$1\frac{1}{2}$	17	$\frac{1}{2}$	750	2	
137	Sept. 28	,, ,,	$1\frac{1}{2}$	13	$\frac{1}{2}$	750	3	
138	Sept. 28	,, ,,	$1\frac{1}{2}$	15	$\frac{1}{2}$	750	3	
139	Sept. 28	,, ,,	$1\frac{1}{2}$	15	$\frac{1}{2}$	600	3	Hand pump.

140	Sept. 30	Kara Ogular (Doiran)	$1\frac{1}{2}$	8	$\frac{1}{4}$	700	flow	Inflow into lake coupled to Merryweather pump, yielded 4,000 gals. per hour. Static level 1 ft. above surface. Driven to rocks.
141	Sept. 30	,, ,, ,,	2	8	$\frac{1}{4}$	1,000	flow.	
142	Oct. 1	Kilindir Doiran Road	$1\frac{1}{2}$	8	$\frac{1}{4}$	750	surface	Sunk to rock in outflow of lake.
143	Oct. 1	Doiran Railway Station	$1\frac{1}{2}$	13	$\frac{1}{2}$	500	6	Sunk in beach to rock.
144	Oct. 2	Doiran Lake-side	$1\frac{1}{2}$	13	$\frac{1}{2}$	600	3	River bed.
145	Oct. 2	Cestovo (Serbia)	$1\frac{1}{2}$	11	$\frac{1}{2}$	700	3	
146	Oct. 3	,, ,,	$1\frac{1}{2}$	25	$1\frac{1}{2}$	nil	—	Sunk into sandy course entering stream, first too high above water-table.
147	Oct. 3	,, ,,	$1\frac{1}{8}$	12	$\frac{1}{2}$	600	6	
148	Oct. 4	Doiran town	$1\frac{1}{2}$	16	$\frac{3}{4}$	700	5	Lake side.
149	Oct. 4	,, (Beach Road)	$1\frac{1}{2}$	9	$\frac{1}{2}$	600	$2\frac{1}{2}$	Lake side.
150	Oct. 4	,, (Railhead)	$1\frac{1}{2}$	13	$\frac{1}{2}$	600	2	On beach formation, near lake for watering masses of troops and labour parties during advance into Bulgaria.
151	Oct. 5	,, ,,	2	10	$\frac{1}{2}$	1,000	2	
152	Oct. 5	,, ,,	2	10	$\frac{1}{2}$	1,000	2	
153	Oct. 6	,, (Lake-side)	$1\frac{1}{2}$	?	?	?	?	
154	Oct. 8	,, (Railway Station)	$1\frac{1}{2}$	15	$\frac{1}{2}$	600	6	
155	Oct. 9	,, (Beach dump)	$1\frac{1}{2}$	?	?	?	?	
156	Oct. ?	Stavros	$1\frac{1}{4}$	10	$\frac{1}{2}$	600	2	Near beach in filled-up bay.
157	Oct. 23	Serres (near Railway Station)	$1\frac{1}{4}$	8	—	240	3	Struma Plain, sands patchy amidst clays. Grey sand.
158	Oct. 23	,, (1 mile west)	$1\frac{1}{2}$	20	—	nil	—	Brown dry sand.
159	Oct. 24	,, ($1\frac{1}{2}$,, ,,)	$1\frac{1}{2}$	19	—	nil	—	Sands, dry.
160	Oct. 25	,, Road ($32\frac{1}{4}$ K.)	$1\frac{1}{2}$	16	—	400	11	Fine brown sand.
161	Oct. 29	,, ,, (75 K.)	$1\frac{1}{2}$	22	—	300	11	
162	Oct. 29	,, ,, (75 K.)	$1\frac{1}{2}$	16	—	400	11	
163	Oct. 30	,, ,, ($79\frac{1}{2}$ K.)	$1\frac{1}{2}$	24	—	nil	—	Only clay.
164	Oct. 31	,, ,, ($88\frac{1}{2}$ K.)	$1\frac{1}{2}$	19	—	100	9	Thin sand bed; clay.
165	Oct. 31	,, ,, (88 K.)	$1\frac{1}{2}$	10	—	nil	—	Clay only.

MACEDONIAN DRIVE TUBE WELLS, 1918—*continued.*

Well No.	Date.	Location.	Tube. Size.	Tube. Depth.	Time. Hours.	Capacity. Gals. per hour.	Water-level. Feet below surface.	Remarks
	1918		inches	feet				
166	Oct. 28	Dedeagatch (near station)	$1\frac{1}{2}$	18	—	700	13	This group of wells driven in river alluvial deposits except 172, 174. The first six wells were completed and in use within six hours of the landing of a division, *all units having a plentiful* supply of good water without touching native sources.
167	Oct. 28	,, (N. Station)	2	20	$\frac{3}{4}$	600	12	
168	Oct. 28	,, (N.E. Station)	$1\frac{1}{2}$	20	1	700	12	
169	Oct. 28	,, (E. Station)	$1\frac{1}{2}$	11	$\frac{1}{3}$	900	5	
170	Oct. 28	,, mile east	$1\frac{1}{2}$	15	$\frac{3}{4}$	600	13	
171	Oct. 28	,, (S. Station)	$1\frac{1}{2}$	15	$\frac{1}{3}$	700	6	
172	Oct. 29	,, R.A.F. ($1\frac{1}{2}$ M.E.)	$1\frac{1}{2}$	18	1	nil	—	
173	Oct. 31	,, Town	$1\frac{1}{2}$	20	1	700	15	
174	Oct. 31	,, R.A.F. ($\frac{1}{2}$ M.E.)	$1\frac{1}{2}$	9	$\frac{1}{4}$	600	4	
175	Oct. 31	,, Town	$1\frac{1}{2}$	20	1	nil	clay	
176	Nov. 1	,, (River bank)	$1\frac{1}{2}$	16	1	600	13	
177	Nov. 2	,, (River bed)	$1\frac{1}{4}$	17	1	600	4	
178	Nov. 3	,, (N.W. Station)	$1\frac{1}{4}$	17	$\frac{3}{4}$	600	13	

GROUP OF WELLS DRIVEN IN SERVIA (MONASTIR AREA).

Well No.	Date.	Location.	Tube.		Time. Hours.	Capacity. Gals. per hour.	Water level. Feet below surface.	Remarks.
			Size.	Depth.				
	1917		inches	feet				
1	Sept. 6	Kenali (centre village)	$1\frac{1}{4}$	37	$2\frac{1}{2}$	nil	—	Only clay after 12 in. sand; dry.
2	Sept. 7	,, ,, ,,	$1\frac{1}{4}$	12	$\frac{1}{2}$	300	6	Sandy zones in clay.
3	Sept. 7	Medzdedli (village)	$1\frac{1}{4}$	22	$1\frac{1}{2}$	nil	—	No sand or water after 7 ft.
4	Sept. 7	,, (dry river-course)	$1\frac{1}{4}$	10	$\frac{1}{2}$	500	6	
5	Sept. 8	Zabjami	$1\frac{1}{4}$	18	$1\frac{1}{4}$	nil	—	All stiff clay after 6 ft.
6	Sept. 8	,, (dry river-course)	$1\frac{1}{4}$	20	$1\frac{3}{4}$	nil	—	Sand to 10 ft., dry, afterwards stiff clay.
7	Sept. 8	,, (near village)	$1\frac{1}{4}$	8	$\frac{1}{4}$	nil	—	Sand, damp only; clay below.
8	Sept. 8	,, (dry river-course)	$1\frac{1}{4}$	7	$\frac{1}{4}$	nil	—	After 7 ft. damp sand only; clay.
9	Sept. 9	Brod (Italian area)	$1\frac{1}{4}$	13	$\frac{1}{2}$	700	6	Near River Cherna.
10	Sept. 9	,, (near village)	$1\frac{1}{4}$	12	$\frac{1}{3}$	500	6	Near River Cherna.
11	Sept. 9	Skocivir (near village)	$1\frac{1}{4}$	16	$\frac{1}{2}$	nil	—	Struck rock or boulder.
12	Sept. 9	,, ,,	$1\frac{1}{4}$	18	1	700	—	Close to above near river bank; water clean and mineralised in pleasant manner.
13	Sept. 9	,, (Russian Hospital)	$1\frac{1}{4}$	28	1	nil	—	Too hard to drive further.
14	Sept. 10	Negotin Cherna (river bed)	$1\frac{1}{4}$	15	$\frac{1}{3}$	nil	—	Clay only.
15	Sept. 10	,, ,, (river bank)	$1\frac{1}{4}$	21	1	nil	—	Hard clay only.
16	Sept. 10	,, ,, ,,	$1\frac{1}{4}$	10	$\frac{1}{2}$	nil	—	Sand to 4 ft., then clay only.
17	Sept. 11	Kenali	$1\frac{1}{4}$	10	$\frac{1}{2}$	nil	—	Dry sand, then clay.
18	Sept. 11	Stredno Egri (river course)	$1\frac{1}{4}$	20	1	nil	—	10 ft. sand, then dry clay.
19	Sept. 11	,, ,, ,,	$1\frac{1}{4}$	15	$\frac{1}{2}$	nil	—	10 ft. dry sand, then clay.

GROUP OF WELLS DRIVEN IN SERVIA (MONASTIR AREA)—*continued.*

Well No.	Date.	Location.	Tube.		Time. Hours.	Capacity. Gals. per hour.	Water-level. Feet below surface.	Remarks.
			Size.	Depth.				
	1917		inches	feet				
20	Sept. 12	Lazec (river course)	$1\frac{1}{4}$	10	1	500	2	These wells in sandy river courses stretching from mountains to plains in which they are usually lost to view
21	Sept. 12	Porodin (side of village)	$1\frac{1}{4}$	8	$\frac{1}{2}$	500	3	
22	Sept. 12	Bristica (village)	$1\frac{1}{4}$	11	$\frac{1}{2}$	500	4	
23	Sept. 13	Dobroveni (near village)	$1\frac{1}{4}$	13	$\frac{1}{2}$	500	8	
24	Sept. 13	Skocivir (Russian Hospital)	$1\frac{1}{4}$	12	$\frac{1}{2}$	500	3	On Cherna River banks.
25	Sept. 13	Slivica (village)	$1\frac{1}{4}$	11	$\frac{1}{2}$	500	9	In small gulley from mountain.
26	Sept. 13	*Zivonia (lignite mines)*	$1\frac{1}{4}$	13	2	nil	—	Very hard consolidated bed.
27	Sept. 13	Dobroveni (roadside)	$1\frac{1}{4}$	27	1	300	8	Fine black sands, very sulphurous, and could not be cleared.
	1918							
28	April 12	,, (M.T.C. base)	2	13	$\frac{1}{2}$	nil	—	
29	April 12	,, (1 mile N.)	2	47	2	nil	—	
30	April 13	,, (1 mile N.)	2	19	$\frac{1}{2}$	700	4	Mineralised water.
31	April 14	,, ($\frac{1}{4}$ mile N.)	2	24	$\frac{3}{4}$	1,000	9	Sands from 10 ft.
32	April 16	,, ($\frac{1}{2}$ mile S.)	2	24	$\frac{3}{4}$	1,200	4	Sands from 10 ft.
33	April 17	,,	2	23	$\frac{3}{4}$	500	7	Sands at 15 ft.
		Total .	.	568	27			

The Serbian wells averaged 17·2 ft. in depth driven at a speed of about 21 ft. per hour with an average time of 49 minutes each.

CHAPTER V

DRILLING WELLS

Geological conditions essential for successful deep drilling—Apparatus and procedure in drilling wells—Drilling records and costs under military conditions.

Geological Conditions Essential for Successful Deep Drilling.—The oft-expressed fallacy prevailing that the deeper one drills the better the prospects for obtaining large supplies of good water should be dispelled for reasons already expressed. In particular cases where peculiar geological and climatic conditions pertain very deep wells alone will yield abundant supplies of water. Generally speaking, any sedimentary series of beds that include sandy zones of fair dimensions and constancy which have not sustained too acute flexuring or metamorphism will yield water in some quantity if situated in areas of moderate rainfall. Even compact crystalline limestones and sandstones often contain water which circulates in an intricate system of crevices or joint cracks which might be missed by many bore-holes. Under such conditions the firing of a heavy charge of high explosive in the well is sometimes effective in establishing connection with a subterranean water-bearing fissure-system.

Some sedimentary beds contain objectionable salts soluble in water, and extracted waters may be too mineralised for potable or even industrial purposes; carbonates, chlorides, sulphates, and sulphides are the most usual constituents, the first named being susceptible to simple treatment if present in excessive quantities. The chlorides, like the carbonates, are comparatively harmless unless in highly concentrated form, whilst the sulphates have a decided laxative effect. Sulphides transmit to the water a disagreeable appearance rather than injurious properties.

After locating a likely series of geological beds consideration must be given to its probable thickness and the depth of saturation before locating a wall. Obviously it would be foolish to expect water in wells that did not exceed the depth of near-by ravines which cut into the beds, draining any porous zones. A description of Macedonian conditions where much successful drilling was performed during the war will illustrate all the principal features that are reproduced elsewhere and have to be considered when locating well sites. The remarkably few failures bear striking testimony to the value of geology in fixing sites, for in many cases the deviation of a hundred yards from the point selected would have meant failure (see Chapter II).

Apparatus and Procedure in Drilling Wells.—Deep-seated waters—that is, water beyond a depth of 50 to 70 ft.—can only be exploited in a reasonable time by drilling. Shaft sinking is far too lengthy and laborious an operation, involving often too many engineering and uncertain problems for emergency purposes when the water lies far below the surface. Until the European war a small hand-worked or power-driven surging plant with a few tools was usually considered adequate for all purposes, and no R.E.'s had been trained in the working of mechanical drilling plant of modern design which drilling for oil has been the medium of bringing to perfection. Fig. 31 shows the usual small gear and tools used.

The operation is too simple to need much explanation. Chisels are attached and lowered on square iron rods, which are dropped after being raised by means of a wire or hemp rope extending from a swivel on the upper rod over a pulley at the top of a tripod or derrick, and thence round the revolving drum of a winch. The drum is worked by power or hand, and if the free end of the rope is coiled round once or twice, a slight pull will create sufficient friction on the drum to cause the tools to be lifted. If, after raising, the rope is quickly released the tools fall and deliver a blow. By rotating the rods a fraction of a revolution after each descent, the stratum is broken up into fragments or puddled into a mud so that it can be removed in augers, bailers, sand pumps, or other devices designed for its extraction.

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PLATE XXXVII.—SURGING RIG AT WORK.
Winch driven by oil engine.

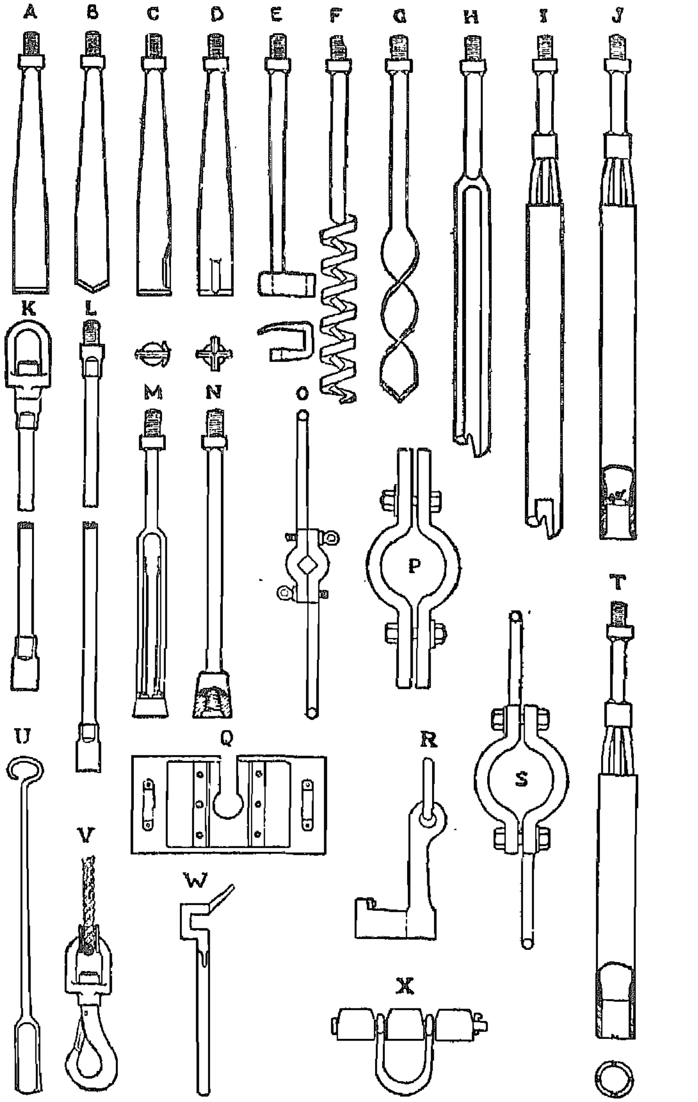


FIG. 31.—Tools for surging drill.

A. Flat chisel.
B. Diamond - pointed chisel.
C. Tee chisel.
D. Cross chisel.
E. Crow's foot.
F. Spiral worm.
G. Worm auger.
H. Auger.
I. Closed auger.
J. Shell.
K. Swivel rod.
L. Boring rod.
M. Bell box.
N. Bell screw.
O. Rod tillers.
P. Pipe clamps.
Q. Auger board.
R. Lifting dog.
S. Pipe tillers.
T. Circular chisel.
U. Auger cleaner.
V. Spring hook.
W. Hand dog.
X. Shear leg joint.

At intervals, lengths of tubing are inserted and driven down as the bore progresses.

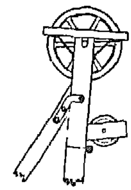
When the War Office decided to adopt modern methods of drilling, the question arose of selecting the best type of the many rigs in the market, and eventually the "Star" portable drill was decided upon. This was a popular American machine very largely used in the United States, and one for which there would be little difficulty in procuring competent operators. The wisdom of this selection was exemplified when the United States joined the war and at once ordered large numbers of the same make of rig for France. Although the machine is far from intricate, and the working is not beyond the powers of any mechanically inclined workman, only long and continuous practice will evolve that skill necessary to effect a high footage rate. Even amongst operators of 20 years' constant experience on the one type of rig there is frequently a difference of 50 per cent. between the rates of drilling, a variation which is in no way associated with laziness or shirking; in fact, the more skilful man usually accomplishes his quicker work with far less physical exertion than the unskilful.

Accurate mental appreciation of the events that are proceeding below ground and a nice judgment as to the intensity or speed of blows administered to beds of various composition are needful. The cleaning of the hole at the most suitable intervals and care to ensure its verticality reduce the risks of accident to a minimum, and effect a maximum speed. The recovery of lost tools under innumerable and ever-varying conditions calls for exceptional skill and experience if long delays and abandoned wells are to be avoided.

For military purposes Star Rig. No. 22 was selected as the most suitable. It is designed for a depth of 800 ft., but in practice it is well to keep it within a limit of 500 to 600 ft. The plant is shown in Fig. 32, where all the essential details of construction are shown. The boiler may be fitted as shown, or mounted separately.

Those employed had the boiler mounted on the rig. The reversing steam engine transmits power to a band wheel 5 ft. 2 in. in diameter, the outer and inner rims being true

faces against which friction pulleys are drawn by levers to operate two other shafts. The main shaft has at the other end to the band wheel a disc crank, to the pin of which is attached a pitman suspended from a walking beam which oscillates about a fulcrum mounted on a stiffly-braced standard. A countershaft driven from the main shaft by friction is connected by gearing to a drum upon which is wound the drilling cable. A second shaft worked by a friction pulley that comes in contact with the inner band wheel face is fitted with a drum that takes the sand-line, *i.e.* the line that actuates the bailers, sand



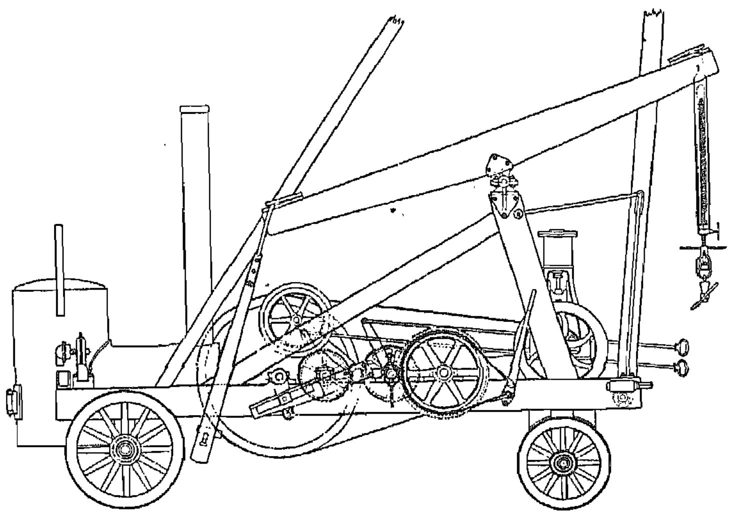


Fig. 32.—Star drilling machine.

pumps, and cleaning devices. The shafts are thrown in and out of operation by levers controlled at the front of the machine near the engine throttle.

Until a depth of one or two hundred feet has been attained it is usual to drill by a process called "spudding." In any case, it is impossible to use the beam until a depth has been reached which will allow the string of tools to be suspended from the walking beam. A $1\frac{1}{2}$-in. diameter manilla cable is usually employed with this rig for drilling

in order to give the desirable elasticity. The spudding apparatus is shown in Fig. 32. By throwing the spudding arm fulcrum behind the driving crank attachment, a quicker descent than ascent of the tools results, thus causing a better blow to be administered by the tools and also reducing the jerk thrown on the cable on the reverse movement. The tools are shown in Fig. 33. They consist of drilling-bits to suit the various sizes of holes; sinker bars to give added weight to the blow, a set of jars and a rope socket to connect the cable. By means of the jars, which act as a flexible union, the string of tools is divided into two parts, the upper being the top link of jars and the rope socket with sometimes the added weight of a bar, and the lower composed of bit, stem, and lower link of jars.

If during the process of drilling, the bit becomes gripped it can generally be released by slackening the rope a little and causing the jars to deliver a powerful blow at each upward stroke. Without the interposition of some such device percussion cable drilling would be almost impossible, as in the event of the tools being stuck the rope would stretch until the strands broke if a steady and increasing pull only were exerted.

Drills or bits are usually made of good steel that will take a fair temper, and they are dressed, not sharpened, so that the bottom edge is nearly flat. The main object of cable drilling is not to cut the rock but to break down its coherence by steady pounding until only a pulverised rock or a puddle of clay results. Were a flat thin chisel edge used there would be a disposition for the drill to enter and stick in soft ground, and in hard ground to strike the same spot repeatedly instead of delivering blows equally all over the base. There would also be a great tendency to deflection and the creation of a flat hole in the case of a flat, sharp-edged object. Continuous blows destroy in time the coherence of the hardest rocks after which the pulverised and puddled material can be easily raised in suitable appliances.

A simple bailer will suffice to clear the well of puddled clay or mud, but heavy, sandy particles which quickly settle when the churning action of the moving drill ceases may

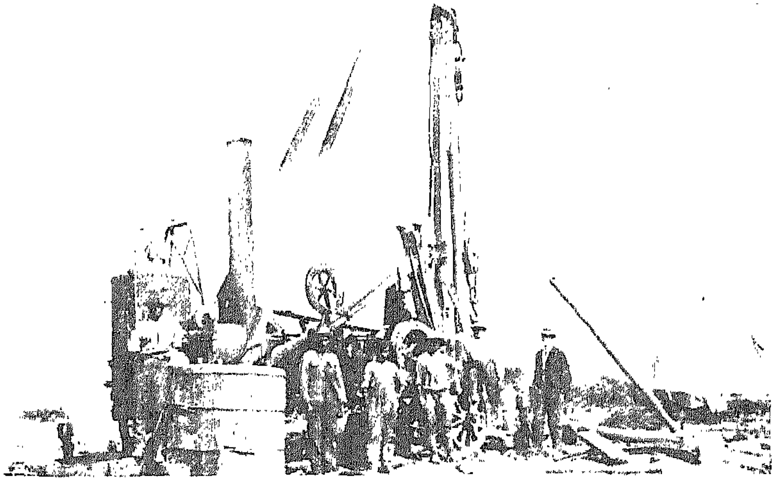


PLATE XXXVIII. STAR DRILLING MACHINE WITH OPERATORS AT SALONIKA.

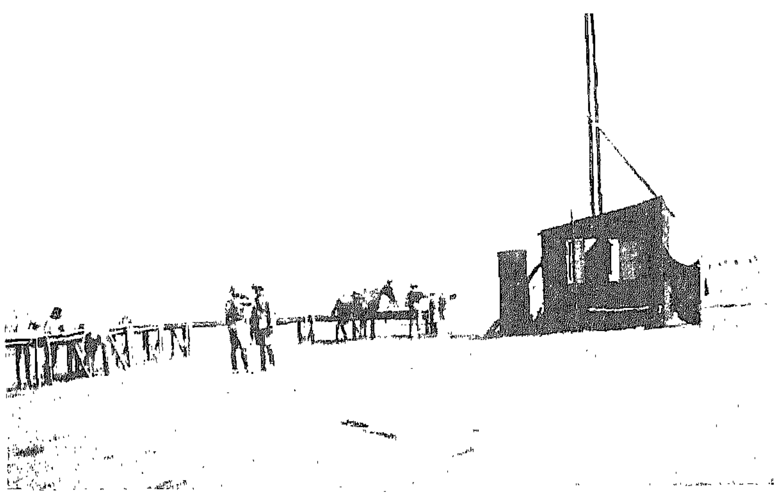


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PLATE XXXIX.—DRILLED WELL EQUIPPED WITH OIL ENGINE AND PUMPS FOR HORSE WATERING AND CAMP SUPPLIES.

Mast on engine-house is for raising pump rods and rising main.

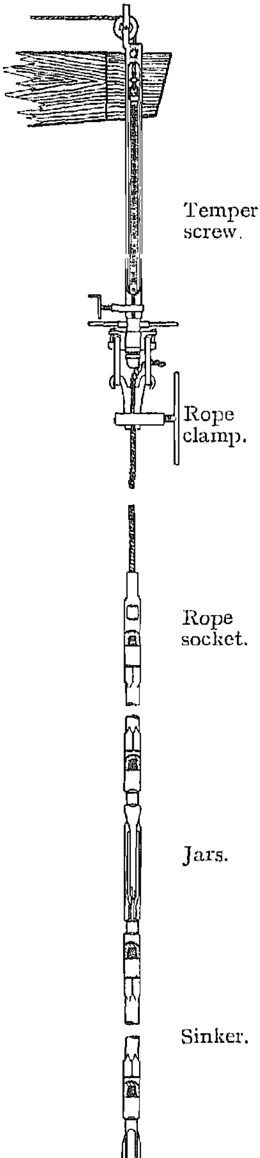


FIG. 33.—String of cable drilling tools.

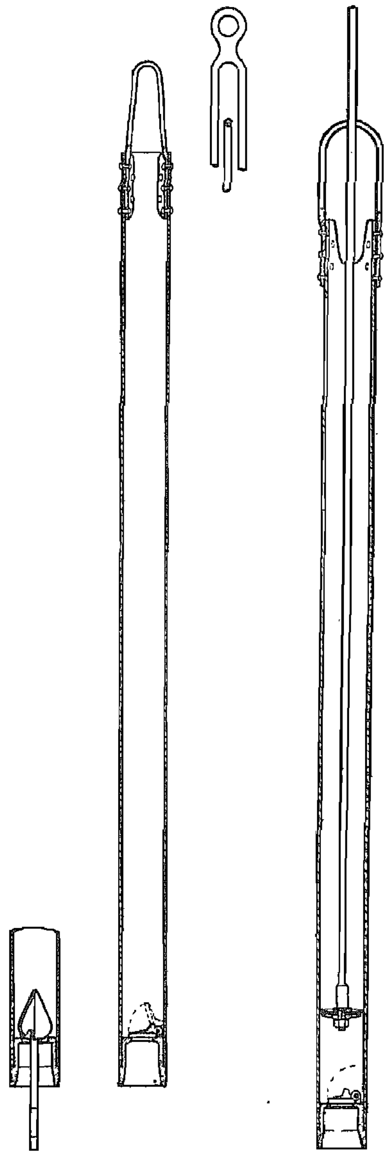


FIG. 34—Cleaning appliances for bore-holes. A, Bailer; B, sand pump.

have to be raised by means of a sand pump into which the material is drawn by the suction action of a rising plunger. Both bailers and sand pumps are repeatedly raised and allowed to fall rapidly in order to churn up the detritus and cause them to sink into the disintegrated material.

Drilling operations are commenced by spudding a fairly large hole, say 14 in. diameter, to a depth of from 10 to 20 ft. A guide column of tube or wood is then lowered to prevent the surface soil from caving and thus endangering the support of the plant. Wooden conductors may be square, round, or octagonal, but the former requires a larger spudded hole to enable the first sized column of tubing to pass freely. When the free movement of the tools is impeded by the thick consistency of the puddled material the cable is removed from the spudding pulley and the tools withdrawn by putting into gear the cable drum which has been thrown out during drilling.

The bailer or sand pump drum is next put into motion, and the bailer, after being raised above the well mouth, is allowed to descend into the hole by gravity. A few trips generally suffice to clear the hole of mud or detrital matter which is discharged into a sump dug on one side of the machine. In cases where there is no water, or insufficient to create a puddle, it is necessary to add sufficient to maintain some 20 ft. in the hole. An excessive amount of water adversely influences progress by reducing the weight of the tools and rope and resisting the free descent by friction. When drilling in a dry hole, about 300 gallons of water a day were necessary for drilling purposes alone, but in some cases where water is absorbed by the beds much larger quantities may be necessary. If water is scarce and too much is being absorbed by the beds the addition of a thick clay puddle may greatly reduce the loss by filling up the pores of the stratum.

So long as the sides of the hole do not break away or "cave," drilling may be continued in an open hole, but as soon as caving commences and material falls on the tools the sides must be supported by casing. If only short distances can be drilled ahead without support it is usual to carry the casing as drilling progresses by driving down the

column of tubes when sufficient hole has been made to admit of a length of tubing being driven home. When very incoherent ground prevails, not more than a few feet of hole being advanced ahead of the casing, specially short lengths of casing are inserted until the troublesome zone is passed. "Running" or "quick" sands arising from a water-saturated body of uncompacted sands can usually be penetrated and passed, if necessary, by cautious bailing during continuous pressure on the pipes. Should the casing not respond it should be driven into the sand body at frequent intervals between bailings or churnings by the drill. At intervals when lateral friction prevents forward progress casing is landed and work is continued with a reduced diameter.

Casing is driven by means of the spudding gear. A steel driving head (Fig. 35) is attached to the top of the casing, and beneath the upper joint of the sinker bar is firmly secured a stout pair of driving clamps (Fig. 35). When the spudding gear is put into action the rope can be so adjusted that a blow is delivered by the clamp at each descent of the tools. Careful adjustment of the speed and suitable feeding out of the cable enable a blow of any desired intensity to be delivered to the driving head. In subsequent drilling it is unnecessary to remove the driving head, as it simply acts as a guide to the rope during work, and can be lifted by fastening on the top of the rope socket when the tools are raised from the well.

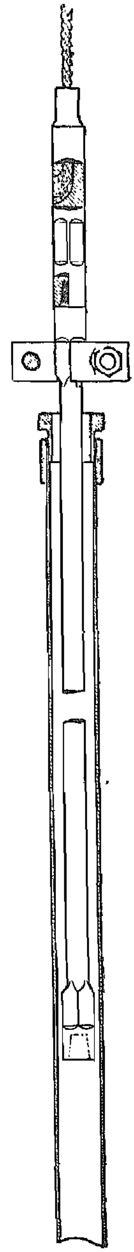


FIG. 35.—Method of driving casing with aid of tools.

Drilling speeds are seriously diminished when working in a long column of liquid owing to the buoyancy of the cable; consequently, undesirable water should be shut off by a string of casing. There are, however, cases where owing to the incoherent nature of the strata, freedom of the casing column or fair progress in drilling is only possible by the maintenance of a high head of water which should be as little depressed as possible during cleaning.

The tightening of tool joints is worth alluding to because neglect or inadequate attention may be the cause of many subsequent difficulties. Under no circumstances should tool joints be left unused without a protector after greasing or oiling to prevent rusting. Before making a joint all dirt should be carefully removed from the threads of box and pin, and finally cleansed by dashing on clean water. After screwing up by hand as far as possible, the joint is tightened by means of powerful jack levers actuating the arms of the wrenches. Instead of the simple perforated circle it is customary to employ a jack-and-rack circle of ingenious design which has acquired almost universal application in the drilling world. The process of jointing up is shown in Fig. 36.

Where no suitable levering apparatus exists the joints can be made by driving up the wrenches by means of heavy sledges. Joints are disconnected by the reverse operation of the wrenches.

Camouflaging Rigs.—The essential mast or derrick in modern drilling rigs is very difficult to conceal from enemy observation in forward positions. At Helles and Anzac during the Gallipoli campaign the mast was moderately concealed by attachment of shrubbery, as was also the rig itself. During visits of enemy aviators work was temporarily suspended to avoid the attention moving objects would attract, and the machine was well sand-bagged to reduce the effect of bombs or gun-fire. Only best Welsh steam coal was used that gave no smoke if properly fired. Several wells were thus drilled unmolested at Helles in full view of enemy positions, although in one case alongside a battery of French guns, the position, being fairly well known to the

Turks, drew fire. A clump of trees was used as a partial screen in one case.

Unfortunately, less success attended efforts at Anzac, where there was no neighbouring vegetation to aid the

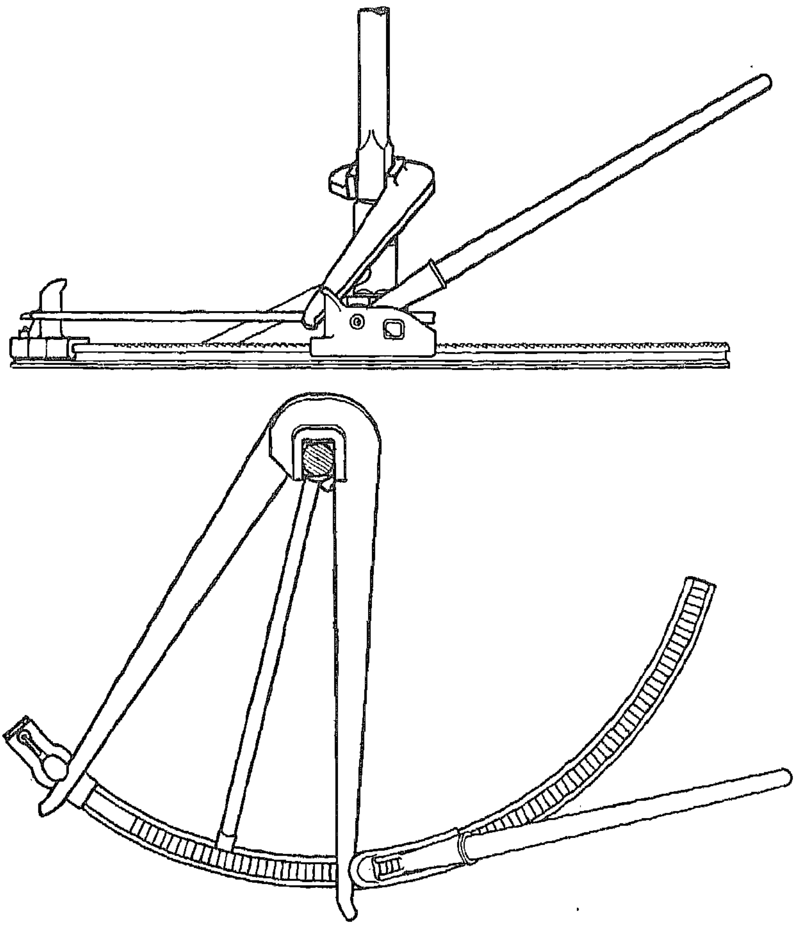
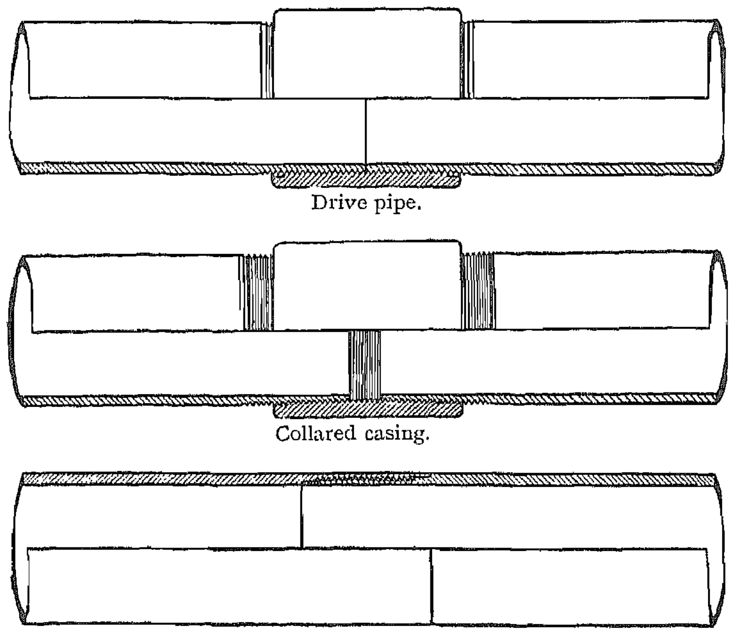


FIG. 36.—Circle and jack for screwing up tool joints.

camouflage and the mast doubtless attracted the attention of the Turks who held commanding positions. In this case, the rig sustained a heavy shelling by shrapnel that caused several casualties, and it had to be moved at night to a less

conspicuous position. No quick process of drilling has been evolved which does not necessitate the erection of some form of mast or derrick.

Lining Tubes and their Manipulations.—The lining tubes for wells may be of three types, viz., flush joint, inserted joint, or collared. In general field practice the last type is selected as being stronger and more enduring for rough



Drive pipe.

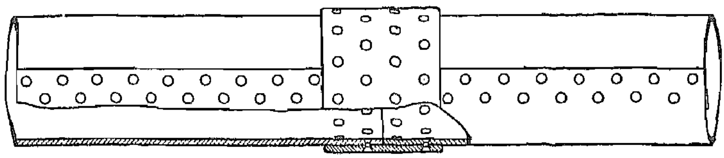
Collared casing.

Flush joint casing.

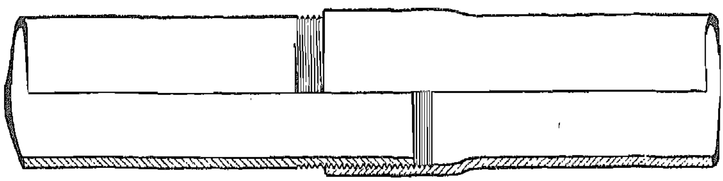
FIG. 37.—Types of lining tubes.

work. Two types of the collared variety are generally distinguished as casing and drive pipe respectively, the former have taper threads and do not butt when firmly screwed up; the latter having coarser but less tapered threads butt when screwed home. Naturally the latter type better resists heavy driving and will withstand greater punishment and rougher treatment than other classes. On the other hand, lighter casing is easier to transport and will often endure the medium treatment which is inflicted upon it in its employment.

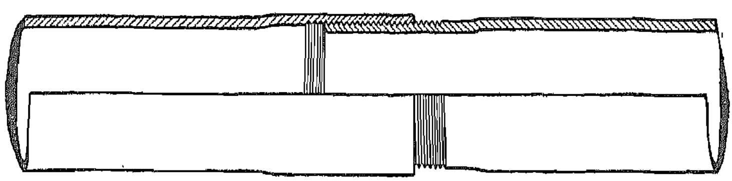
It will be at once realised that flush and inserted joint pipes allow of a smaller reduction of size for each string than a succession of collared or socketed tubes; also that a flush-jointed column offers less resistance than a socketed string, which must necessarily require a larger hole for its passage; nevertheless, these advantages of flush and inserted joint pipes are largely nullified by their liability



Stove pipe or riveted casing.



Inserted joint casing.



Swelled and crest inserted joint casing.

FIG. 38.—Types of lining tubes.

to damage when driven, and the difficulties of repairing a bulged or faulty internally-screwed end.

When inserting a column, clamps or elevators are generally employed, but any suitable device can be used. Thus the column is often lifted by means of a short piece of screwed pipe to which a bail is riveted. In all cases the block and tackle for lifting has a swivel hook attached to the lower block so that rotation of the casing does not twist the ropes.

In wells of small diameter it is usual to arrange for the

lowest few joints to be perforated so that a larger infiltration area is provided when the water-bearing bed is deeply penetrated. Sometimes a plain length is added below the perforated portion to enable the bore-hole to be carried completely through the water-bed into unproductive strata in which the lower length forms both an anchor and a sump for detritus. In lieu of perforations, sand screens are often used when the sands cause trouble by constant entry during pumping (see Fig. 40).

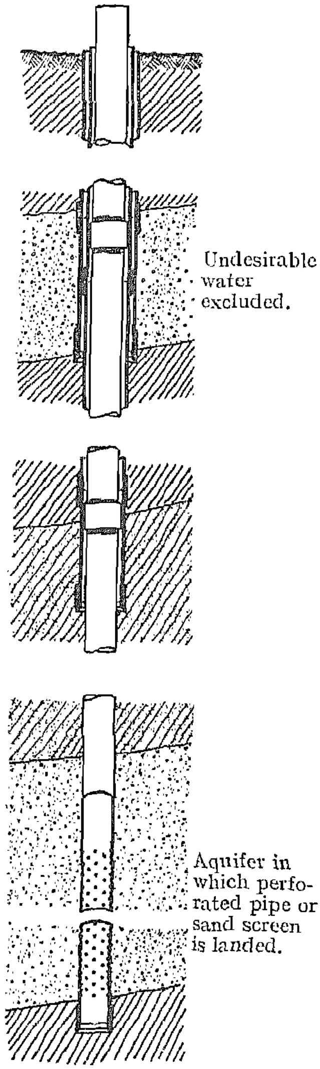


FIG. 39.—Sections of completed well.

To the bottom of the lower tube is generally affixed a steel shoe with cutting edge that will shear the wall of the bore-hole when driven down. It is unwise to dispense with this shoe as it affords so much protection to the casing in the event of encountering obstructions.

A "frozen" column of tubing may be generally freed by means of the pulley blocks, but if this fails to effect freedom jacks can be operated below heavy clamps bolted to the casing. After jacking up for a distance exceeding that between two successive collars the casing can generally be handled with the blocks. Release is frequently aided by alternate jacking and driving. The introduction of water into the hole will

often assist by causing a flow behind the tubes thus disintegrating packing of sand. Many other expedients are possible in case of necessity, but these hardly come within the province of work of the nature under discussion. Such methods as punching, slitting, or cutting the casing, or firing charges of explosives, are resorted to in special

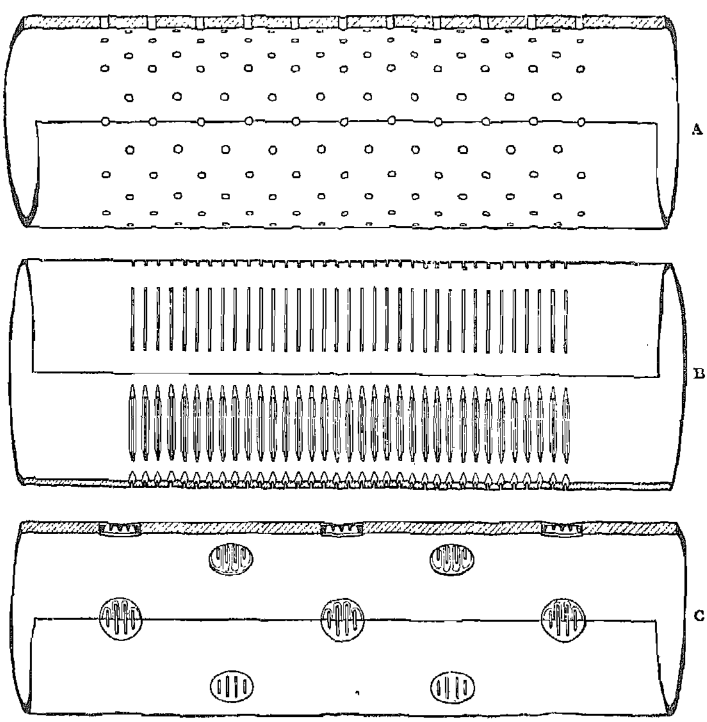


FIG. 40.—Perforated pipe and sand screens.
A, Ordinary perforations; B, slotted pipe with larger internal dimensions; C, inserted slotted buttons.

cases. Fig. 41 shows a jacking operation and the apparatus used for the purpose. Either screw or hydraulic jacks can be used.

Portable rigs never have a mast suitable for handling heavy strings of piping, and a separate erection is usual from which the pulley blocks are suspended and the casing worked. Such a suitable shear legs consists of two tubular

standards of 6-in. or 8-in. casing connected by a cross-piece of strong timber at the top. The legs are extended at the base to span the floor, and are held in place by wire guy-ropes, back, front, and sides leading from the top to the anchor bolts.

Casing Accidents.—During the manipulation of casing a joint sometimes parts at a moment when it is impolitic to stop a string of casing before reducing diameter. A

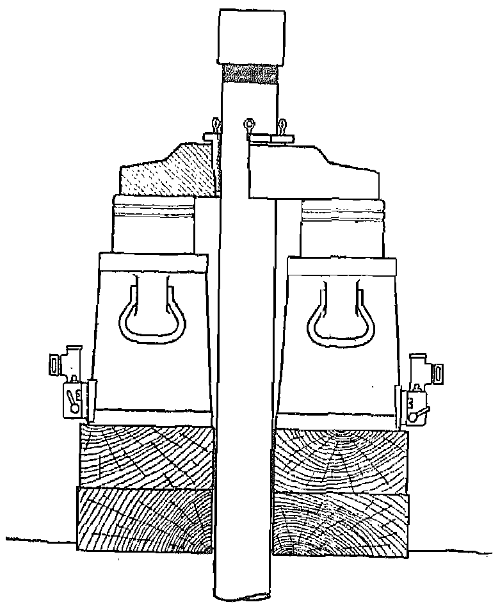


FIG. 41.—Jacking up frozen casing with hydraulic jacks.

new connection can often be made by relowering the column with a new end-piece slightly tapered. The upper column can then be screwed tightly into position by power from the rig. If this fails a steel-screwed, tapered, fluted plug or collar, as requirements may dictate, can be lowered and firmly screwed into position, after which the lost section may be withdrawn and the faulty joint replaced. The use of the more elaborate casing "spears" is rarely necessary in comparatively shallow water wells. More detailed information

concerning drilling methods may be found in "Oilfield Development," published by Crosby Lockwood and Son.

Sometimes casing becomes bulged by excessive lateral pressure or at a weakened spot. A fluted swedge will often

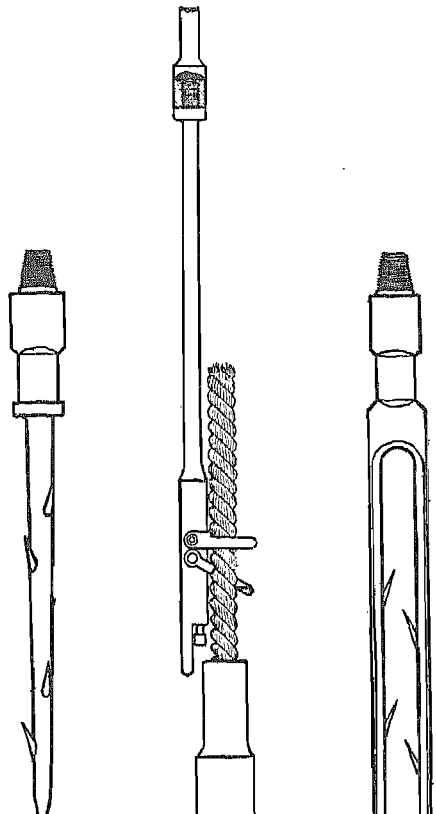


FIG. 42.—Rope grabs and rope knife.

repair the damage, but more often the removal of the column is a simpler operation.

Recovery of Lost Tools.—The quick and successful recovery of lost, broken, buried, or jammed tools entails precise judgment, quick decisions, and skilful manipulation of such fishing appliances as may be available. In this operation more than any other, experience is of great service.

The chief accidents are attributable to—

(*a*) Breakage of cable as a result of damaged fibre or jamming of tools.
(*b*) Unscrewing of a tool joint, or dropping of tools.
(*c*) Jamming of tools by cavings, fall of rock, or swelling clays.
(*d*) Collapse of casing around or above tools.
(*e*) Burying of tools by inrush of sand.
(*f*) Breakage of tools, generally at joints.

An unscrewed tool in a clean hole can generally be grabbed sufficiently firmly by a friction hold. A taper mandril heavily driven over the lost object will grip it sufficiently firmly to allow its removal. More often, however, there are complications that render the process less simple. If the cable break it is nearly always necessary to extract the rope that coils itself in confusion above the tools. This is effected by means of one of the rope grabs shown in Fig. 42, which, when driven down, secures a grip. If the tools rise with the rope so much the better, but if not, the rope is jarred till it breaks. Unless it severs just above the rope socket the operation is repeated until the rope socket top is clear of obstruction.

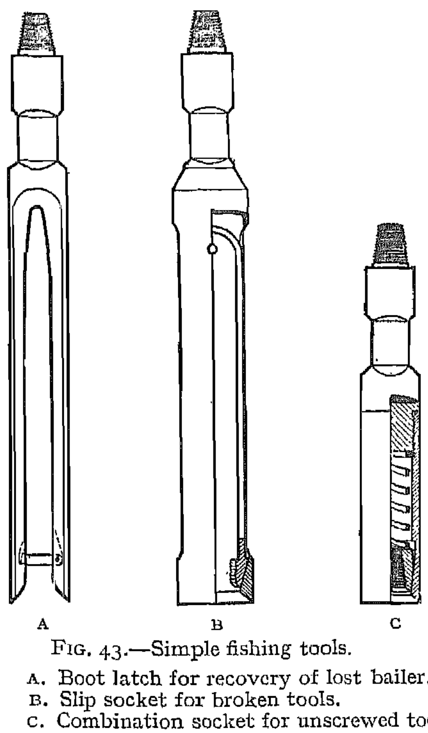
All fishing tools should be lowered on a new string of tools in which a set of long-link fishing jars is incorporated, for with such an elastic medium as hempen cable reliance is exclusively placed upon the upward blows that can be administered by the jars.

When exceptional difficulties are anticipated or encountered it is usual to lower fishing tools on iron poles or a string of casing which furnishes positive connection between the surface and the lost tools, and allows much more latitude in the choice of implements and the pressure exerted.

When a friction hold is too insecure to effect release some sort of slip socket is lowered that will pass over the lost tools. Such a simple tool is shown in Fig. 44 descending over a lost string. During descent the two slips are kept distended in their upper position by a small strip of wood that is knocked aside immediately it is touched by any object introduced. The slips thus released drop into side-

tapered slots and seize the enclosed object, after which the stronger the upward force applied the firmer the grasp.

An admirable and commendable practice is to sketch to scale the presumed position of the lost tools in the well in order to appreciate all possible contingencies, for in some cases, as where the fracture has occurred just beneath the shoe of the tubes or the lost portion has been driven aside into the wall of the hole, the tools may incline to one side and not present a face over which a hollow instrument could pass. Under most conditions it is customary to take the precaution of attaching to the slips a suitably sized conical guide-piece that will fill the hole and direct the tool squarely over the lost object. It is likewise essential to have



A B C

FIG. 43.—Simple fishing tools.

A. Boot latch for recovery of lost bailer.
B. Slip socket for broken tools.
C. Combination socket for unscrewed tools.

FIG. 44.—Slip socket in use.

the correct dimensions of all drilling tools in use, without which convenient fishing tools cannot be arranged or designed.

In those cases where the lost tools incline to one side or have been driven into the walls of the well they must be drawn into a central position before fishing tools can secure a hold. For this purpose a long spud is lowered and worked in the well, a few balls of clay being at the same time inserted if the tools fall again out of position on the removal of the tool. Sometimes it may be necessary to lower a hooked tool on rods or casing so that it can be forcibly rotated around the tightly-wedged tools whilst given a reciprocating motion.

When the bits become jammed by a fall of ground above them release is usually possible by patient jarring upwards through the obstruction. If this fails a long side spud may help, or, in special cases, light tools may be used to drill out the material. When sandy, the offending mass may be washed away by using a string of small pipes through which a powerful flush of water is maintained. A big inrush of sand over the tools can only be removed with wash tubes, a strain being maintained on the drilling cable whilst the jet is being slowly lowered into the sand.

The collapse of casing above or around the tools generally necessitates the extraction of the column of casing with the enclosed tools, a somewhat lengthy and tedious operation. Bulges of casing above the tools may be repaired by inserting swedges, a process that entails the cutting off of the rope above the rope socket by a rope knife, illustrated in Fig. 42.

It is impossible to describe or to imagine the endless varieties of accidents and troubles that arise in drilling. When the condition of the hole or tools is unknown it is sometimes actually possible to see the state of affairs in dry holes by projecting a ray of sunlight down the hole with a mirror or using a powerful electric torch. The position of submerged tools may be ascertained by lowering a seal or impression block consisting of a flat layer of soft shellac and resin, or bitumen deposited on a disc and lowered on to the lost object which leaves an impression. Depths should be accurately measured by the sand-line or a steel tape.

Small objects accidentally dropped into a well, or a short piece of steel broken off the bit, may be picked up by *tongs*, forks, or augers rotated on rods, but if all efforts fail it is usual to drill the articles up, or, in the case of hard bodies, drive them aside into the walls of the bore-hole if the stratum is not too hard. Lost bailers can be recovered by a grab or hook, such as is shown in Fig. 43. Quite often lost objects can be recovered by bailers into the valve of which they become stuck.

More elaborate tools than those described do not call for remark when dealing with the comparative shallow well drilling under discussion, as it is usually cheaper to drill a new well than to waste much time on a difficult fishing job. For deep drilling where wells reach 2,000 ft. to 6,000 ft. deep, elaborate, and very expensive tools are employed to overcome troubles which inevitably arise whatever precautions be taken.

Simple fishing tools can be improvised by any intelligent operator who has no specially prepared appliances at hand. A quite useful friction socket can be made by denting with a hammer a length of casing or tubing sufficiently just to permit it being forced over a lost object. Similarly a few strips may be riveted on the inside of a pipe so that their upper free ends are sprung inwards. On raising such a tube after lowering over a projection on a lost tool one or more slips catch beneath the projection and enable the lost tool to be raised. Occasionally an unscrewed tool joint can be reconnected by rotating the rope whilst the disconnected ends are in contact.

Drilling Records and Costs.—The attached tabular statements and graphs are taken direct from the writer's note-book, and indicate a convenient way of methodically recording and graphing the work in progress. Table 1 gives the monthly footage drilled during three years, both total and for each well. Fig. 45 gives the footage graphs. Table 2 is a list of all wells drilled with their locations, dates, approximate yield, casing left in wells, and water-levels.

Fig. 46 illustrates a very convenient way of keeping

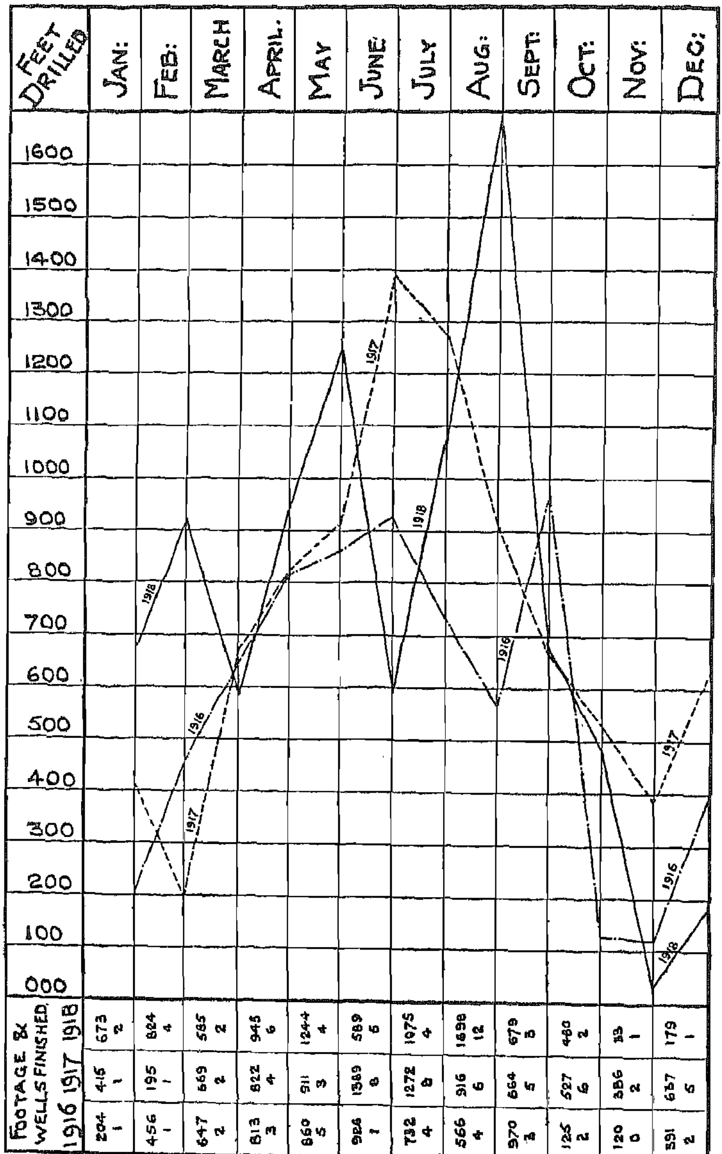


FIG. 45.—Graphic representation of footage drilled.

well logs so that all data is at once available should a question arise about any well :—

WELL No. —.

Commenced, Jan. 15.	Driller, Jones.
Finished, Jan. 30.	Rig, 22 Star.

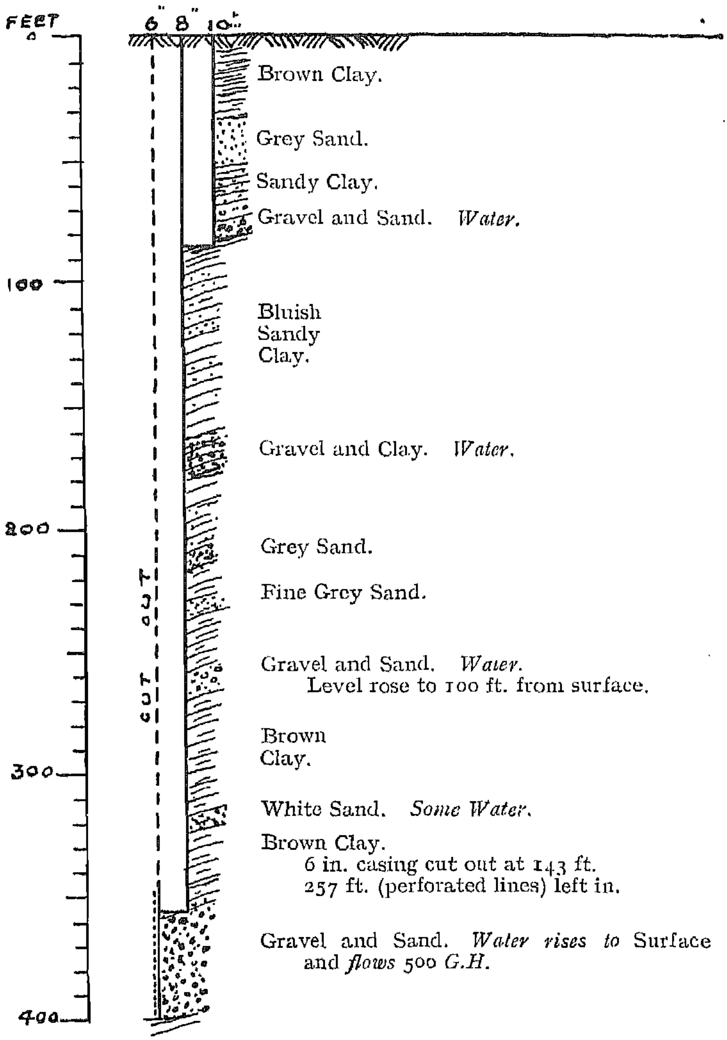


FIG. 46.—Sample section of well.

Cost of Drilled Wells.—Attached tables give the approximate cost of all wells. In this list prices of materials have been approximately averaged as those of every consignment of goods varied, and 35 per cent. was added to f.o.b. prices for shipping transport. Motor lorries are charged up at £5 per day. All labour is charged up at civil rates, rations at Army costs. American operators received $200.00 monthly in addition to Army rations, medical treatment, etc. Moderate depreciation was added to cover repairs in Army workshops and maintenance.

A fair average value of £8 10*s*. per rig day was arrived at, so that wells averaging 200 ft. in depth cost £190 each in addition to the casing that averaged £36 per well.

The plant and material to accomplish the described results cost approximately £125,000 delivered Salonika. In the winter months only a small proportion was in use, whilst during the summer all rigs were often fully employed, and high tension was often imposed on the staff. At times the distances separating successive wells caused long periods of unavoidable inactivity in drilling. Enforced delays for material and transport frequently made the costs far in excess of those which would have been incurred under normal circumstances. The health of the operators was likewise reflected in the work at times, especially in the malarial zones of the Struma and Vardar. Taking all circumstances into consideration, the results are creditable, and compare favourably with peace-time prices in England and Europe.

Drilling speeds differed considerably according to the nature of the strata, but the difference in skill of the operators was very marked. The best day's run of 10 hours resulted in 110 ft., or 11 ft. per hour, but speeds of from 40 ft. to 55 ft. per day were frequent. The average rate per drilling day of 8 hours was about 25 ft.; in this figure is included any day on which any footage was made. Often hours would be lost waiting for water for boiler, casing, or tools, at times when transport was scarce or the weather bad.

In the foregoing pages no mention has been made of flushing systems, but if deep wells have to be sunk in unconsolidated sands, it is often possible to use a flush drill that washes the material away as casing is inserted.

SPECIFICATION OF STAR RIG OUTFIT AND TOOLS

1 No. 22 Non-Traction Star Drilling Machine, complete with two main belts, engine, boiler, bullock pole and mast, and mounted on iron wheels with 10-in. rims.

1 Ball Bearing I. Beam Derrick Crane, complete with one 1-ton Harrington Hoist and one No. 2 Barrett Swivel Wrench for $3\frac{1}{4}$-in. squares.

1 *No. 1 Double-Acting Barrett Oil Well Jack, with circle complete.*

1 set Tool Wrenches for $3\frac{1}{4}$-in. squares, 150 lbs. each.

1 $1\frac{3}{8}$-in. Mannington Pattern Temper Screw, with elevator head and lower parts for $1\frac{5}{8}$-in. Manilla cable, let out 5 ft. to suit Walking Beam of No. 22 Star Machine.

2 Sub Rope Sockets for $1\frac{5}{8}$-in. Manilla cable, 2 in. × 3 in., 8 sharp OWS threads, $3\frac{1}{4}$ in. square.

1 set $4\frac{3}{8}$-in. diameter Regular Pattern Drilling Jars, $4\frac{1}{2}$-in. stroke, 2 in. × 3 in., 8 sharp *OWS threads, $3\frac{1}{4}$ in. square.*

3 $3\frac{1}{2}$ in. × 10 ft. Auger Stems, 2 in. × 3 in., 8 sharp OWS, $3\frac{1}{4}$ in. square.

2 $12\frac{1}{2}$-in. Light Pattern Spudding Bits, length 3 ft., width $11\frac{1}{2}$ in., 2 in. × 3 in., 8 sharp OWS. $3\frac{1}{4}$ in. square. Est. wt., 320 lbs. each.

$1\frac{1}{2}$ sets (3) 10-in. All Steel Regular Pattern Drilling Bits, to run in 10-in. Drive Pipe, 2 in. × 3 in., 8 sharp threads, $3\frac{1}{4}$ in. square. Est. wt. per set, 1060 lbs.

$1\frac{1}{2}$ sets (3) 8-in. All Steel Regular Pattern Drilling Bits, to run in 8-in. Drive Pipe, 2 in. × 3 in., 8 sharp threads, $3\frac{1}{4}$ in. square. Est, wt. per set, 800 lbs.

$1\frac{1}{2}$ sets (3) $6\frac{5}{8}$-in. All Steel Regular Pattern Drilling Bits, to run in $6\frac{5}{8}$-in. casing, 2 in. × 3 in., 8 sharp OWS threads, $3\frac{1}{4}$ in. square. Est. wt. per set, 750 lbs.

$1\frac{1}{2}$ sets (3) $5\frac{3}{16}$-in. All Steel Regular Pattern Drilling Bits, to run in $5\frac{3}{16}$-in. casing, 2 in. × 3 in., 8 sharp OWS, $3\frac{1}{4}$ in. square. Est. wt. per set, 400 lbs.

1 $12\frac{1}{2}$-in. Bit Gauge. 1 10-in. Bit Gauge. 1 8-in. Bit Gauge.

1 $6\frac{5}{8}$-in. Bit Gauge. 1 $5\frac{3}{16}$-in. Bit Gauge.

1 Conductor Bailer, 10 in. diameter × 10 ft. long.

1 9-in. × 199-ft. Regular Wrought Iron Dart Bottom Bailer.

1 7-in. × 1-ft. ditto. 1 $5\frac{1}{2}$-in. × 19-ft. ditto. 1 $4\frac{1}{4}$-in. × 19-ft. ditto.

1 Spare Bail and Valve for each of the above.

1 7-in. "Oilwell" Sand Pump for use in 8-in. hole.

1 4-in. "Oilwell" Sand Pump for use in $5\frac{3}{16}$-in. hole.

1 set $4\frac{1}{2}$-in. × $4\frac{1}{2}$-in. × 14-in. Drive Clamps, complete with $2\frac{1}{4}$-in. × 15-in. bolts and nuts, also Wrench for $3\frac{1}{4}$ in. square.

1 set Spares $2\frac{1}{4}$-in. × 15-in. bolts for above.

1 Stub Box, 2 in. × 3 in., 8 sharp OWS, scarfed for welding.

1 *Stub Pin, 2 in. × 3 in.*, 8 sharp OWS, *scarfed for welding.*

1 set Wilson Light Pattern Spring Latch Elevators for 10-in. drive pipe without links.

1 set do. for 8-in. drive pipe, less links. 1 set do. for $6\frac{5}{8}$-in. casing, less links.

1 set do. for $5\frac{3}{16}$-in. casing, less links. 2 $2\frac{1}{2}$-in. × 72-in. Links for above.

1 10-in. Jack Ring or Spider, with one set 10-in. × 10-in. Wedges.

1 10-in. × 8-in. Jack Ring Bushing. 1 set 8-in. × 8-in. Jack Ring Wedges.

1 8-in. × $6\frac{5}{8}$-in. Jack Ring Bushing. 1 set $6\frac{5}{8}$-in. × $6\frac{5}{8}$-in. Jack Ring Wedges.

1 set $6\frac{5}{8}$-in. × $5\frac{3}{16}$-in. Jack Ring Wedges.

1 Type "C" Light Dunn Tong for 10-in. drive pipe, with spare bushings to take 8-in. drive pipe, $6\frac{5}{8}$-in. and $5\frac{3}{16}$-in. casings.

1 set Back-up Tongs.

2 pairs each Vulcan Flat-link Chain Tongs, Nos. $13\frac{1}{2}$ and 15.

1 spare Chain for each of the above.

1 22-in. "Oilwell" All Steel Pulley Block, single, with bronze bushing, and suitable for $\frac{3}{4}$-in. wire line.

1 22-in. "Oilwell" All Steel Pulley Block, double, with bronze bushing for $\frac{3}{4}$-in. wire line.

1 $4\frac{1}{2}$-in. Double-swivel Casing Hook.

2 $1\frac{5}{8}$-in. × 600-ft. Best Philadelphia Manilla Drilling Cable, hawser laid, weighing approximately 1 lb. per ft.

1 $\frac{1}{2}$-in. × 900-ft. Steel Wire Sand Line, right-hand lay, 6 × 7 construction.

1 $\frac{5}{8}$-in. × 120-ft. Regular Cast Steel Casing Line, 6 × 19 construction, right-hand lay.

Fishing Tools :

1 Horse-shoe Trip Rope Knife for $1\frac{5}{8}$-in. Manilla cable, complete with jars and sinker.

1 Two-wing Rope Grab, to run in $6\frac{5}{8}$-in. casing, 2 in. × 3 in., 8 OWS.

1 Regular Rope Spear, to run in $5\frac{3}{16}$-in. casing, 2 in. × 3 in., 8 OWS.

1 Bailer Grab, to run in $5\frac{3}{16}$-in. casing, 2 in. × 3 in., 8 OWS.

1 set $4\frac{3}{8}$-*in. diameter Fishing Jars*, Regular Pattern, 30-in. stroke, 2 in. × 3 in., 8 sharp OWS threads.

1 Regular Pattern Slip Socket, for $6\frac{5}{8}$-in. casing, 2 in. × 3 in., 8 sharp OWS threads, with bowls for 8-in. and 10-in. drive pipe, and two extra sets of slips to catch 2 in. × 3 in. 8 sharp threads OWS joint.

Sundries :

2 60-ton Hydraulic Jacks, Double Plunger, Single Outside Pump, 12-in. raise.

1 Measuring Line, 750 ft., with "Oilwell" reel and weight.

1 No. 3 Iron Tool Box, 24 in. wide, 78 in. long, 19 in. to 21 in. high.

Parkersburg Tank :

1 Parkersburg Improved Portable Bolted Steel Tank, 12 ga. throughout, knocked down with Outside Ladder. Capacity, 200 bbls. Regular construction, complete with all necessary angles, plates, bolts and rivets for constructing this tank on site.

TABULATED LIST OF FOOTAGE DRILLED MONTHLY AT SALONIKA FRONT.

1916.

Jan.		Feb.		Mar.		Apr.		May.		June.		July.		Aug.		Sept.		Oct.		Nov.		Dec.		
Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	
1	204	2	253	3	240	5	31	7	84	13	141	14	128	18	113	22	70	24	45	28	120	26	234	
—	—	3	103	4	85	6	49	9	43	14	258	15	90	19	15	23	195	27	80	—	—	28	157	
—	—	4	100	5	216	7	282	10	176	15	285	16	16	20	203	24	370	—	—	—	—	—	—	
—	—	—	—	6	106	8	220	11	202	16	190	17	154	21	95	25	200	—	—	—	—	—	—	
—	—	—	—	—	—	9	231	12	200	17	52	18	214	22	140	27	135	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	13	155	—	—	19	130	—	—	—	—	—	—	—	—	—	—	
—	204	—	456	—	647	—	813	—	860	—	926	—	732	—	566	—	970	—	125	—	120	—	391	6,810

1917.

Jan.		Feb.		Mar.		Apr.		May.		June.		July.		Aug.		Sept.		Oct.		Nov.		Dec.		
Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	
29	215	29	135	31	5	32	13	37	35	40	49	46	30	—	—	62	10	67	6	73	33	76	19	
30	200	31	60	32	268	34	39	38	110	41	131	48	98	56	67	63	85	68	66	74	121	77	214	
—	—	—	—	33	260	35	280	39	245	42	105	50	137	57	85	64	180	69	97	76	167	78	85	
—	—	—	—	34	136	36	330	40	201	43	105	51	163	58	37	65	145	70	150	77	65	79	85	
—	—	—	—	—	—	37	160	41	145	44	184	52	67	59	165	66	94	71	132	—	—	80	88	
—	—	—	—	—	—	—	—	42	100	45	157	53	179	60	150	67	150	72	76	—	—	81	146	
—	—	—	—	—	—	—	—	43	75	46	240	54	215	61	155	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	47	100	55	55	62	257	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	48	208	56	101	—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	49	75	57	84	—	—	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	50	35	58	143	—	—	—	—	—	—	—	—	—	—	
—	415	—	195	—	669	—	822	—	911	—	1,389	—	1,272	—	916	—	664	—	527	—	386	—	637	8,803

TABULATED LIST OF FOOTAGE DRILLED MONTHLY AT SALONIKA FRONT—*continued.*

1918.

Jan.		Feb.		Mar.		Apr.		May.		June.		July.		Aug.		Sept.		Oct.		Nov.		Dec.		
Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	Wells.	Feet.	
77	221	77	162	77	13	90	45	95	172	99	45	105	183	108	55	119	162	122	18	123	33	125	179	
82	156	85	163	88	140	91	350	96	180	101	68	106	181	109	68	120	177	123	300	—	—	—	—	
83	157	86	152	89	197	92	142	97	172	102	136	107	110	100	160	121	184	124	162	—	—	—	—	
84	139	87	144	90	235	93	174	98	80	103	260	108	215	108	176	122	156	—	—	—	—	—	—	
—	—	88	170	—	—	94	169	99	330	104	80	109	226	111	160	—	—	—	—	—	—	—	—	
—	—	84	33	—	—	89	63	100	172	—	—	110	160	112	176	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	101	138	—	—	—	—	113	146	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	—	—	—	—	114	161	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	—	—	—	—	115	81	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	—	—	—	—	116	230	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	—	—	—	—	117	165	—	—	—	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	—	—	—	—	118	120	—	—	—	—	—	—	—	—	
—	673	—	824	—	585	—	943	—	1,244	—	589	—	1,075	—	1,698	—	679	—	480	—	33	—	179	9,002

WELLS DRILLED IN SALONIKA AREA OCCUPIED FOR ALLIED ARMIES.

1916.

Well No.	Location.	Dates.		Total days.	Drill-ing days.	Work-ing days.	Rate per drilling day.	Depth in ft.	Capacity Gals. per hour.	Levels.		Casing.			
		Commenced.	Finished.							Well above sea.	Water from surface.	10 in.	8 in.	6 in.	5 in.
1	Ordnance, Monastir Road	Jan. 20	Feb. 2	14	9	14	22·7	204	400	—	flow	—	133	195	—
2	A.S.C. Main Dump	Feb. 4	Feb. 22	19	10	19	25·3	253	750	—	flow	—	—	220	252
3	Summer Hill Rest Camp	Feb. 25	Mar. 26	30	20	29	17·1	343	1,500	—	93 ft.	—	203	342	—
4	Kalamaria	Feb. 25	Mar. 11	15	10	15	18·5	185	1,000	—	60 ft.	—	89	151	—
5	,,	Mar. 21	April 10	21	12	21	20·6	247	2,000	—	90 ft.	—	247	—	—
6	Lembert Road	Mar. 28	April 5	9	7	9	22·1	155	500	—	flow	—	117	—	58
7	,, ,,	April 9	May 20	42	30	39	12·2	366	1,000	—	flow	—	214	134	—
8	Kalamaria	April 12	April 27	16	10	15	32·0	320	1,000	—	100 ft.	—	215	220	—
9	Harmankeui (Deepened)	April 18 } July 25	Aug. 28	53	36	51	12·9	465	1,000	—	flow	—	—	461	—
10	Kalamaria	May 3	May 18	16	10	16	17·6	176	1,000		100 ft.	—	176	—	—
11	Monastir Road Bakery	May 8	May 18	11	8	11	25·3	202	1,000	—	flow	—	123	200	—
12	Lembert Road	May 23	June 5	14	8	14	25·0	200	1,000	—	30 ft.	—	106	200	—
13	,, ,,	May 27	June 22	27	20	25	14·8	296	1,500		10 ft.	—	167	—	—
14	Monastir Road Remounts (Deepened)	June 2 } July 5	July 19	35	28	33	13·2	370	700	—	50 ft.	—	154	369	—

15	Kalamaria	June 16	July 22	37	18	34	20·8	375	nil	—	nil	—	150	45	—
16	Dudular Vet. Hosp.	June 24	July 2	9	8	9	25·7	206	1,200	—	flow	—	164	206	—
17	Akbunar Road, Lembert	June 29	July 14	16	10	16	20·6	206	1,000	—	20 ft.	—	177	65	—
18	Summer Hill	July 17	Aug. 9	24	15·5	22	20·4	315	1,000	—	flow	—	301	41	—
19	Kalamaria	July 25	Aug. 12	19	9	19	16·1	145	1,000	—	25 ft.	—	128	—	45
20	,,	Aug. 16	Aug. 28	13	10	11	20·3	203	500	—	flow (250 gals. p.h.)	—	114	—	203
21	Dudular 28th Gen. Hospital	Aug. 20	Aug. 25	6	3	6	31·7	95	—	—	flow (100 gals. p.h.)	—	—	—	105
22	Dudular 28th Gen. Hospital	Aug. 26	Sept. 16	22	11	18	19·1	210	550	—	flow (500 (gals. p.h.)	—	134	22	220
23	Dudular Sidings	Sept. 1	Sept. 17	17	12	15	16·1	195	1,000	—	flow	—	144	—	69
24	Janes Railway Station	Sept. 3	Oct. 11	39	31	39	13·4	415	250	—	100 ft.	—	166	314	90
25	Kalamaria	Sept. 21	Sept. 30	10	9	10	22·2	200	1,000		50 ft.		126	200	—
26	Dudular 28th Gen. Hospital	Dec. 1	Dec. 24	24	15	24	15·6	234	—	—	flow	—	184	234	—
27	Kalamaria	Sept. 26	Oct. 11	16	10	16	21·5	215	1,000	—	40 ft.	—	182	215	—
28	,,	Nov. 25	Dec. 4	10	8	10	19·6	157	—	—	50 ft.	—	89	157	—

Number of wells drilled	28	Average days per well	20·8
Total feet drilled	6,953	,, drilling days	13·8
,, rig days	584	,, working days	20·0
Drilling days	387·5	,, casing per well	322 ft.
Total casing	9,036 ft.	,, feet per drilling day	18·0
Average depth	248·3 ft.	,, casing per foot drilled	1·3 ft.

WELLS DRILLED IN SALONIKA AREA OCCUPIED FOR ALLIED ARMIES—*continued.*

1917.

Well No.	Location.	Dates.		Total days.	Drill-ing days.	Work-ing days.	Rate per drilling day.	Depth in ft.	Capacity. Gals. per hour.	Levels.		Casing.			
		Commenced.	Finished.							Well above sea.	Water from surface.	10 in.	8 in.	6 in.	5 in.
29	Sariguel	Jan. 31	Feb. 24	25	25	24	14·0	350	180	—	60 ft.	—	—	150	—
30	Dudular Ordnance	Feb. 18	Mar. 3	14	10	13	20·0	200	480	—	flow	—	156	200	—
31	Summer Hill Laundry	Feb. 25	Mar. 6	10	5	9	13·0	65	2,000	—	35 ft.	—	60	—	—
32	,, ,, ,,	Mar. 12	April 6	25	20	25	13·7	275	50	—	flow	—	200	273	—
33	Mikra G.H.	Mar. 11	Mar. 29	19	11	18	23·6	260	1,000	—	70 ft.	—	204	68	—
34	Serres Road, K. 68	Mar. 20	April 4	16	15	15	13·0	195	30	—	155 ft.	—	40	—	—
35	Marsh Pier Railway	April 9	May 3	25	12	20	22·3	280	700	—	1 ft.	—	—	—	—
36	Struma	April 7	May 6	30	15	27	22·0	330	—	—	—	—	—	290	—
37	Kalamaria Fr. Hosp.	April 23	May 5	13	9	11	21·7	195	1,000	—	10 ft.	—	173	35	—
38	,, ,,	May 8	May 13	6	4	6	27·5	110	1,000	—	flow	—	88	33	—
39	Mikra Bay	May 18	May 25	8	7	8	35·0	245	2,000	—	3 ft.	—	210	45	—
40	Karaburun	May 20	June 11	23	15	21	16·6	250	1,000	—	78 ft.	—	212	58	—
41	Flag Staff Hill	May 23	June 26	35	19	31	14·5	276	1,000	—	78 ft.	—	188	258	—
42	Dudular Zeitenlik	May 24	June 9	17	11	14	18·6	205	2,000	—	10 ft.	21	57	—	—
43	Kalamaria	May 29	June 8	11	7	10	25·8	180	1,200	—	70 ft.	—	118	168	—
44	Karaburun	June 12	June 18	7	5	7	36·8	184	1,000	—	134 ft.	—	184	—	—
45	Galiko Salonika Water Supply	June 12	June 21	10	7	8	22·4	157	1,800	—	flow	20	160	—	—
46	Kalamaria	June 16	July 16	31	10	31	27·0	270	1,000	—	50 ft.	—	—	266	—
47	Galiko Salonika Water Supply	June 23	June 28	6	3	5	33·3	100	1,000	—	flow	—	100	—	—
48	Karaburun	June 27	July 5	9	3	8	69·0	203	1,000	—	150 ft.	—	—	208	—
49	Galiko Salonika Water Supply	June 30	July 6	7	4	6	43·0	173	2,500	—	flow	—	177	—	—
50	Serres Road, 63rd G.H	June 30	July 14	15	9	14	16·0	172	700	—	50 ft.	—	—	136	—
51	Galiko Salonika Water Supply	July 10	July 13	4	4	4	41·0	165	700	—	flow	—	166	—	—
52	Mikra Bay Remounts	July 15	July 21	7	2	7	33·5	67	1,000	—	8 ft.	—	—	67	—
53	Galiko Salonika Water Supply	July 17	July 27	11	7	9	25·6	179	1,200	—	flow	178	—	—	—
54	Kalamaria	July 23	July 31	9	5	8	43·0	215	1,000	—	23 ft.	—	209	—	—

55	Marsh Pier	July 17	July 22	6	2	6	27·5	55	1,000	—	1 ft.	51	—	—	—
56	Adv. Base Park, R.E.	July 27	Aug. 11	16	8	13	19·4	155	600	—	2 ft.	—	110	167	—
57	Struma, K. 68½, Serres Road	July 27	Aug. 12	17	13	17	13·0	169	80	—	30 ft.	—	84	—	—
58	Galiko Salonika Water Supply	July 30	Aug. 10	12	7	12	25·7	180	—	—	flow	24	140	176	—
59	Seddes	Aug. 5	Aug. 13	9	3	6	55·0	165	1,000	—	36 ft.	—	21	164	—
60	Zeitenlik, Italian Base	Aug. 13	Sept. 5	24	9	23	17·0	150	500	—	10 ft.	—	125	—	—
61	Seddes Village	Aug. 15	Aug. 17	3	3	3	52·0	155	500	—	30 ft.	—	33	143	—
62	Niccalav (Struma)	Aug. 14	Sept. 8	26	15	25	17·8	267	1,000	—	10 ft.	—	—	267	—
63	Little Karaburun	Sept. 4	Sept. 7	4	3	4	30·0	90	1,800	—	12 ft.	—	53	85	—
64	Tekali Vet. Farm	Sept. 9	Sept. 22	14	11	13	16·4	180	—	—	—	—	170	—	—
65	Seddes	Sept. 14	Sept. 20	7	4	6	36·3	145	1,500	—	50 ft.	—	—	145	—
66	Tekali Vet. Farm	Sept. 25	Sept. 27	3	3	3	32·0	95	500	—	flow	94	—	—	—
67	Dautbali (1)	Sept. 27	Oct. 1	5	5	5	31·0	156	800	—	10 ft.	—	—	—	155
68	R.E. Base Park	Oct. 4	Oct. 6	3	3	3	22·0	66	1,000	—	10 ft.	—	—	66	—
69	Olympus Brewery	Oct. 6	Oct. 10	5	4	5	24·2	97	3,000	—	4 ft.	—	97	—	—
70	Bralo Rest Camp	Oct. 9	Oct. 12	4	4	4	37·5	150	900	—	83 ft.	—	—	132	—
71	Dautbali (2)	Oct. 14	Oct. 21	8	4	8	33·0	132	1,000	—	12 ft.	—	—	132	—
72	Itea Rest Camp	Oct. 24	Oct. 27	4	4	4	19·0	76	1,000	60 ft.	45 ft.	—	—	76	—
73	R.E. Dump, Dudular	Oct. 30	Nov. 7	9	5	8	16·0	80	960	—	20 ft.	—	74	—	—
74	Dautbali (3)	Nov. 1	Nov. 7	7	3	7	40·0	121	960	470 ft.	25 ft.	—	—	122	—
75	Topolio	—	—	—	—	—	—	—	—	—	—	—	—	—	—
76	Dautbali (4)	Nov. 23	Dec. 6	14	9	14	21·0	186	—	—	2 ft.	—	—	186	—
77	French Depôt, Zeitenlik	Nov. 24	Mar. 12, 1918	109	79	102	8·7	680	—	12 ft.	35 ft.	—	55	600	—
78	Itea	Dec. 9	Dec. 11	3	3	3	28·0	83	1,000	—	25 ft.	—	65	—	—
79	Dautbali (5)	Dec. 9	Dec. 19	11	4	9	21·0	85	500	—	40 ft.	—	—	83	—
80	Bralo	Dec. 20	Dec. 23	4	4	4	22·0	88	1,000	—	28 ft.	—	—	36	—
81	Dautbali (6)	Dec. 20	Jan. 3, 1918	15	8	12	18·0	146	1,000	—	14 ft.	—	—	143	—

Number of wells	52
Total feet drilled	9,268
Total days engaged	735
Drilling days	464
Total casing	9,298 ft.
Average depth	178·1 ft.

Average days per well	14·15
„ drilling days	8·90
„ working days	13·05
„ casing per well	179 ft.
„ feet per drilling day	20·0
„ casing per foot drilled	1·01

WELLS DRILLED IN SALONIKA AREA OCCUPIED FOR ALLIED ARMIES—*continued.*

1918

Well No.	Location.	Dates.		Total days.	Drilling days.	Working days.	Rate per drilling day.	Depth in ft.	Capacity. Gals. per hour.	Levels.		Casing.			
		Commenced.	Finished.							Well above sea.	Water from surface.	10 in.	8 in.	6 in.	5 in.
82	Dautbali (7)	Jan. 13	Jan. 25	13	9	13	17·5	156	760	470 ft.	6 ft.	—	—	153	—
83	Dudular	Jan. 24	Jan. 26	3	3	3	52·0	157	960	—	flow	—	—	154	—
84	Dautbali (8)	Jan. 18	Feb. 6	10	6	10	29·0	172	820	470 ft.	19 ft.	—	—	144	—
85	Dudular	Feb. 6	Feb. 10	5	3	3	54·0	163	850	—	30 ft.	—	—	103	—
86	Dautbali (9)	Feb. 7	Feb. 15	9	6	9	25·0	152	900	470 ft.	12 ft.	—	—	150	—
87	,, (10)	Feb. 15	Feb. 27	13	7	8	20·5	144	1,000	470 ft.	14 ft.	—	—	140	—
88	Summer Hill	Feb. 23	Mar. 16	22	12	20	25·8	310	1,600	460 ft.	70 ft.	—	—	306	—
89	Base Laundry G.H.Q.	Mar. 19	April 9	22	16	21	15·2	200	960	—	flow	—	—	255	—
90	Summer Hill Camp	Mar. 19	April 6	19	10	19	28·0	280	1,100	—	65 ft.	—	—	265	—
91	64th General Hospital	April 9	April 29	21	11	20	32·0	350	—	—	—	—	—	42	—
92	Struma Valley	April 12	April 25	14	6	7	24·0	142	1,000	—	75 ft.	—	141	—	—
93	Karaburun Hospitals	April 19	April 23	5	3	5	58·0	174	800	110 ft.	110 ft.	—	—	170	—
94	,, ,,	April 25	April 29	5	4	5	42·0	169	800	110 ft.	110 ft.	—	—	168	—
95	,, ,,	May 1	May 5	5	4	5	43·0	172	800	112 ft.	112 ft.	—	—	170	—
96	,, ,,	May 6	May 10	5	4	5	45·0	180	800	114 ft.	114 ft.	—	—	180	—
97	,, ,,	May 11	May 15	5	4	5	43·0	172	800	114 ft.	114 ft.	—	—	169	—
98	Larissa Station	May 9	May 13	5	2	4	40·0	80	1,000	—	24 ft.	—	—	—	80
99	Summer Hill Laundry	May 13	June 7	26	15	23	25·0	375	850	410 ft.	50 ft.	—	—	230	—
100	137 A.T.C., Bralo	May 15	May 22	8	4	7	43·0	172	800	—	72 ft.	—	—	145	—
101	½ K., Naresh Road	May 26	June 8	14	12	14	17·0	206	200	—	flow	—	20	—	187
102	913 M.T.C., Bralo	June 5	June 11	7	7	7	19·5	136	1,000	—	flow	—	—	136	—
103	½ K., Naresh Road	June 11	June 30	20	17	20	15·5	260	500	—	flow	—	20	95	246
104	Larissa Station	June 21	June 22	2	2	2	40·0	80	800	—	32 ft.	—	—	—	80
105	Dautbali	July 5	July 17	13	9	12	20·5	183	800	—	12 ft.	—	—	181	—
106	Kapujula American Red Cross	July 9	July 17	9	6	9	30·0	181	1,200	140 ft.	125 ft.	—	—	175	—

107	Harmankeui Fat Works	July 15	July 19	5	5	5	22·0	110	1,000	—	2 ft.	—	—	—	109
108	Mikra American Farm	July 20	Aug. 8	20	7	15	38·5	270	800	260 ft.	flow	—	—	125	150
109	Kalamaria Jewish Quarters	July 24	Aug. 10	18	15	16	19·5	294	350	—	flow	—	240	—	—
110	Karaburun	July 26	July 31	6	6	6	27·0	160	700	—	110 ft.	—	—	156	—
111	,,	Aug. 2	Aug. 8	7	5	7	32·0	160	900	—	100 ft.	—	—	158	—
112	Harmankeui	Aug. 11	Aug. 31	21	14	19	12·5	176	1,000	—	60 ft.	—	175	—	—
113	Karaburun	Aug. 10	Aug. 13	4	3	4	49·0	146	900	—	115 ft.	—	—	146	—
114	,,	Aug. 15	Aug. 20	6	4	6	40·0	161	900	—	120 ft.	—	—	156	—
115	Serres Road, 17 Vet. Hospital	Aug. 16	Aug. 19	4	4	4	20·2	81	2,000	200 ft.	14 ft.	—	—	78	—
116	Kapujula Savarikes Farm	Aug. 17	Aug. 30	14	7	10	33·0	230	1,000	160 ft.	60 ft.	—	200	40	—
117	Karaburun	Aug. 21	Aug. 27	7	6	6	27·5	165	1,000	—	113 ft.	—	—	162	—
118	Galiko Prisoners of War Camp	Aug. 23	Aug. 29	7	4	4	30·0	120	—	10 ft.	flow	—	—	120	—
119	Salonika Quay	Sept. 6	Sept. 17	12	7	11	23·0	162	4,000	6 ft.	flow	—	40	156	—
120	Lembert (Horse Transport)	Sept. 7	Sept. 19	13	7	16	25·0	177	2,000	230 ft.	40 ft.	—	102	77	—
121	Kalamaria Greek Camp	Sept. 20	Sept. 24	5	5	5	37·0	184	1,500	—	—	—	180	—	—
122	Dudular	Sept. 24	Oct. 5	12	9	12	19·5	174	1,000	—	16 ft.	—	153	—	—
123	Summer Hill	Oct. 1	Nov. 14	45	28	34	12·0	333	1,000	—	—	—	332	—	—
124	Naresh Road, 4th K.	Oct. 10	Nov. 17	38	11	27	18·5	203	5,000	—	—	—	154	72	—
125	Agricultural Park	Dec. 12	Dec. 22	11	9	10	20·0	180	700	—	—	—	179	—	—

Number of wells	44
Total feet drilled	8,312
Total days engaged	535
Drilling days	338
Total casing	7,825 ft.
Average depth	189 ft.

Average days per well	12·1
,, drilling days	7·69
,, working days	10·75
,, casing per well	178 ft.
,, feet per drilling day	24·6
,, casing per foot drilled	0·942

TABLE I.—FRENCH WELLS COST SHEET.

Item.	Well No. 6.	£	s.	d.	Well No. 15.	£	s.	d.	Well No. 19.	£	s.	d.	Well No. 20.	£	s.	d.
Total depth	155 ft.				375 ft.				145 ft.				203 ft.			
Total time, including transport	12 days				39 days				21 days, including days' test				15 days			
$8\frac{1}{4}$-in. casing at 50 cents per foot: quantity, weight, cost	117 ft. 2,340 lbs. $85				— — —				— — —				— — —			
8-in. drive pipe at 67 cents per foot: quantity, weight, cost.	— — —				150 ft. 4,500 lbs. $105				128 ft. 2,975 lbs. $85.75				114 ft. 3,306 lbs. $$76\frac{1}{4}$			
$6\frac{5}{8}$-in. casing at 38 cents per foot: quantity, weight, cost.	— — —				45 ft. 765 lbs. $17				— — —				— — —			
$5\frac{3}{16}$-in. casing at 30 cents per foot: quantity, weight, cost.	58 ft. 754 lbs. $17.5				— — —				45 ft. 585 lbs. $13.50				203 ft. 2,639 lbs. $71.0			
Shoes: size, weight, cost	$8\frac{1}{4}$ in. 36 lbs. $4.5				— — —								$5\frac{3}{16}$ in. 1 lb. $3.0			
Total cost at $4.65=£1	—	22	8	0		23	5	0		21	1	0		30	0	0
Freight on casing at £10 per ton	3,130 lbs.	13	16	0	5,265 lbs.	23	12	0	3,560 lbs.	16	0	0	5,945 lbs.	26	0	0
Pumps, rising main, rods, jack, and freight	—	—	—	—	— —	—	—	—	—	18	16	0	—	—	—	—
Clamps: size, number, cost	$8\frac{1}{4}''$, 1 pair	1	0	0	— —	—	—	—	8", 1 pair	1	0	0	8", 1 pair	1	0	0
Sills: size, number, cost	8"×8"×8', 2	1	10	0	— —	—	—	—	8"×8"×8', 2	1	10	0	8"×8"×8', 2	1	10	0
Coal, tons, at £5 per ton	4 tons	20	0	0	$9\frac{1}{4}$ tons	46	5	0	$4\frac{3}{4}$ tons	23	15	0	$3\frac{1}{4}$ tons	16	5	0
Lubricants at 4*s.* per gallon	$3\frac{1}{4}$ gals.		13	0	$12\frac{1}{2}$ gals.	2	10	0	$6\frac{1}{2}$ gals.	1	6	0	$4\frac{1}{2}$ gals.		18	0
Transport, local, at £5 per day per lorry	—	24	2	0	—	61	12	0	—	39	2	0	—	29	3	0
Staff salaries, and sundries, proportion	—	24	12	0	—	80	0	0	—	43	1	0	—	30	16	0
Drillers' and assistants' wages	—	43	9	0	—	93	0	0	—	56	0	0	—	40	0	0
Yard charges, proportion of	—	9	5	0	—	30	0	0	—	16	4	0	—	11	11	0
General expenses	—	8	16	0	—	28	12	0	—	15	15	0	—	11	5	0
Depreciation at 50 per cent. per annum on drilling-machine and tools, value £1,250	—	20	12	0	—	66	18	0	—	35	18	0	—	25	12	0
Total cost		190	3	0		455	14	0		289	8	0		224	0	0

TABLE II.—COST OF DEEP WELLS IN BASE AREA.

No. of well.	Cost of drilling. £ s. d.	Cost of casing. £ s. d.	Cost of pump. £ s. d.	Cost of engine. £ s. d.	Cost of engine and pump installation. £ s. d.	Total. £ s. d.
1	119 0 0	83 0 9	130 0 0	90 2 6	20 0 0	442 3 3
2	161 10 0	78 13 0	—	—	—	240 3 0
3	263 10 0	136 0 1	165 10 0	90 2 6	20 0 0	675 2 7
4	136 0 0	60 9 2	165 10 0	90 2 6	20 0 0	472 1 8
5	127 10 0	89 1 0	205 10 0	90 2 6	20 0 0	532 3 6
7	204 0 0	99 11 3	50 0 0	86 16 0	20 0 0	460 7 3
8	136 0 0	109 15 10	188 0 0	90 2 6	20 0 0	543 18 4
9	459 0 0	103 17 5	—	—	—	562 17 5
10	136 0 0	57 4 0	225 0 0	88 0 0	20 0 0	526 4 0
11	93 10 0	80 16 2	50 0 0	90 2 6	20 0 0	334 8 8
12	119 0 0	75 5 8	225 0 0	86 16 0	20 0 0	526 1 8
13	229 10 0	54 5 6	165 10 0	33 0 0	20 0 0	502 5 6
14	332 0 0	125 5 9	188 0 0	55 0 0	20 0 0	720 5 9
16	76 10 0	97 7 1	188 0 0	33 0 0	20 0 0	414 17 1
17	136 0 0	70 16 0	188 0 0	86 16 0	20 0 0	501 12 0
18	204 0 0	106 3 11	225 0 0	88 0 0	20 0 0	643 3 11
21	51 0 0	13 6 8	—	—	—	64 6 8
22	187 0 0	87 6 8	188 0 0	86 16 0	20 0 0	569 2 8
23	144 10 0	56 0 0	188 0 0	33 0 0	20 0 0	441 10 0
25	85 0 0	81 15 8	188 0 0	86 16 0	20 0 0	461 11 8
26	204 0 0	107 9 6	188 0 0	86 16 0	20 0 0	606 5 6
27	136 0 0	103 1 0	188 0 0	86 16 0	20 0 0	533 17 0
30	127 10 0	91 10 8	188 0 0	86 16 0	20 0 0	513 16 8
31	85 0 0	19 10 0	188 0 0	86 16 0	20 0 0	399 6 0
32	221 0 0	120 14 9	188 0 0	—	10 0 0	539 14 9
33	161 10 0	80 3 8	188 0 0	86 16 0	20 0 0	536 9 8
Totals .	£4,335 10 0	£2,118 11 2	£4,051 0 0	£1,738 15 0	£450 0 0	£12,763 16 2

TABLE II.—*continued.*

No. of well.		Cost of drilling.	Cost of casing.	Cost of pump.	Cost of engine.	Cost of engine and pump installation.	Total.
		£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
35		212 10 0	55 4 9	—	—	—	267 14 9
40		195 10 0	80 14 10	—	—	—	276 4 10
41		297 10 0	113 15 6	188 0 0	86 16 0	20 0 0	706 1 6
44		51 0 0	59 16 0	188 0 0	86 16 0	20 0 0	405 12 0
48		68 0 0	42 13 5	188 0 0	86 16 0	20 0 0	405 9 5
50		110 10 0	27 15 4	188 0 0	86 16 0	20 0 0	433 1 4
52		59 10 0	13 13 7	—	—	—	73 3 7
55		51 0 0	22 19 0	20 0 0	33 0 0	10 0 0	130 19 0
56		144 10 0	69 16 11	188 0 0	86 16 0	20 0 0	509 2 11
67	Dautbali Group.	170 0 0	18 6 8	46 0 0	—	—	—
74		68 0 0	24 18 2	46 0 0	—	—	—
76		119 0 0	37 17 10	46 0 0	—	—	—
79		93 10 0	26 19 6	46 0 0	—	—	—
81		136 0 0	29 8 0	46 0 0	86 16 0	—	—
82		119 0 0	31 8 10	46 0 0	Central power	120 0 0	2,094 12 11
84		85 0 0	33 9 8	46 0 0	32 15 0	—	—
86		85 0 0	30 12 6	46 0 0	—	—	—
87		110 10 0	28 11 8	46 0 0	—	—	—
105		110 10 0	36 19 1	46 0 0	—	—	—
68		25 10 0	13 9 6	188 0 0	86 16 0	20 0 0	333 15 6
69		51 0 0	31 10 6	200 0 0	(with pump)	—	282 10 0
71		69 0 0	26 19 0	188 0 0	86 16 0	20 0 0	390 15 0
73		85 0 0	24 7 6	50 0 0	86 16 0	20 0 0	266 3 6
83		25 10 0	31 8 10	188 0 0	86 16 0	20 0 0	351 14 10
85		51 0 0	33 5 7	188 0 0	86 16 0	20 0 0	379 1 7
88		221 0 0	71 9 6	188 0 0	86 16 0	20 0 0	587 5 6
Totals .		£2,814 10 0	£1,017 11 8	£2,610 0 0	£1,107 7 0	£350 0 0	£7,899 8 2

TABLE II—*continued*

No. of well.		Cost of drilling. £ s. d.	Cost of casing. £ s. d.	Cost of pump. £ s. d.	Cost of engine. £ s. d.	Cost of engine and pump installation. £ s. d.	Total. £ s. d.
89		195 10 0	82 17 6	188 0 0	86 16 0	20 0 0	573 3 6
90		161 10 0	74 11 7	188 0 0	86 16 0	20 0 0	530 17 7
91		195 10 0	8 11 6	—	—	—	204 1 6
93	Karaburun Group.	42 10 0	34 14 2	—	—	—	—
94		51 0 0	34 6 0	—	—	—	—
95		51 0 0	34 14 2	—	—	—	—
96		42 10 0	36 15 0	—	150 0 0 (12 h.p., portable)	—	—
97		42 10 0	34 10 1	460 0 0	—	120 0 0	1,581 1 3
110		51 0 0	31 17 0	—	pumping power	—	—
111		59 10 0	32 5 2	—	32 15 0	—	—
113		34 0 0	29 16 2	—	—	—	—
114		51 0 0	31 17 0	—	—	—	—
117		59 10 0	33 1 6	—	—	—	—
99		221 0 0	107 7 8	188 0 0	86 16 0	20 0 0	623 3 8
101		68 0 0	31 8 8	—	—	—	99 8 8
103		170 0 0	58 13 7	—	—	—	228 13 7
107		59 10 0	14 10 8	5 0 0	—	—	79 0 8
112		178 10 0	35 14 7	188 0 0	86 16 0	20 0 0	509 0 7
115		34 0 0	15 8 6	232 0 0	(with pump)	—	281 8 6
118		59 10 0	24 10 0	75 0 0	(with pump)	—	159 0 0
119		102 0 0	44 17 0	98 7 0	86 16 0	20 0 0	352 0 0
120		110 10 0	48 4 4	—	—	—	158 14 4
122		110 10 0	48 14 6	130 0 0	90 2 6	20 0 0	399 7 0
123		416 10 0	107 18 0	188 0 0	66 0 0	20 0 0	798 8 0
124		357 0 0	64 15 0	—	—	—	421 15 0
125		110 10 0	58 3 6	188 0 0	86 16 0	20 0 0	463 9 6
Totals .		£3,034 10 0	£1,160 2 10	£2,128 7 0	£859 13 6	£280 0 0	£7,462 13 4
Grand Totals		£10,184 10 0	£4,366 5 8	£8,789 7 0	£3,705 15 6	£1,080 0 0	£28,125 17 8

CHAPTER VI

PUMPING EQUIPMENT AND WATER ANALYSES

Notes on the selection of pumping equipment—Notes on the character of waters.

Notes on the Selection of Pumping Equipment.—There is no intention of doing more than roughly describing the various kinds of pumps and mechanical appliances used for the raising and transmission of water. The best type for a specific duty must be decided by circumstances, and only the facts that guide one in determining a process or type will be enumerated.

Water-raising and distributing appliances can be appropriately divided into the following main groups :—

For Surface Uses Mainly	Reciprocating Plunger Type.	Direct-driven, steam pumps, single or compounded, horizontal or vertical. Duplex steam-driven pumps, single or compounded, horizontal or vertical. Merryweather type steam fire pump with boiler attached. Single, double or treble throw ram pumps, horizontal or vertical, direct-coupled, or driven by belt or gearing by some motive power.
	Rotary Type.	Centrifugals, single or multi-stage turbine type, horizontal or vertical. Roto-plunge, screw or drum pumps. Semi-rotary type. Archimedian screw.
	Unclassed Types.	Diaphragm pump. Hydraulic ram. Syphon. Humphrey gas pump. Pulsometer.
For Shafts or Bore-holes.	Ejector Type.	Steam ejectors or aspirators. Air-lift or air-displacement.
	Sundry Types.	Bailing. Swabbing. Deep well lift pump, single or double acting (Downey) Bucket, chain or rope pump. Single, double or triplex lift pump operated by rods. Vertical multi-stage turbine.

Pumps may be portable, stationary, or semi-portable, direct driven, by steam engine or other motor, or geared or belt driven by separate power unit, such as steam engine, turbine, internal combustion engine, or electrical motor if electricity is available. Pumps may also be horizontal or vertical, slow or fast running, and designed for high or low pressures. Experience on active field service indicated the importance of standardising both types and sizes, even at some sacrifice of efficiency for particular duties. Steam pumps were studiously avoided in the field on account of the scarcity of suitable fuel, and the smoke caused by boilers within enemy observation. Exception is only made in the case of the Merryweather fire pump, which was self-contained and portable, and could be put into use at the shortest notice for special purposes. Apart from its value on particular occasions it was a constant source of anxiety, owing to the rapidity at which it lost water, and the need for incessant and skilled attention. Scarcely a boiler that came under the writer's observation escaped damage in the Salonika campaign.

For surface duties the following considerations influenced the selection of size and type for military purposes :—

(*a*) Capacity for average requirements.
(*b*) Weight and bulk for transport.
(*c*) Speed of erection.
(*d*) Simplicity of design.
(*e*) Reliability in running.
(*f*) Efficiency.
(*g*) Maximum head (static and friction) likely to be required.
(*h*) Fuel.

Owing to the varied conditions it was eventually generally agreed that in the M.E.F. operations the following points should be observed in ordering :—

(*a*) Separate engines and pumps were advisable so that the combination could be varied to suit the duty.
(*b*) A fair average sized unit was 1,500 to 2,000 gallons per hour.
(*c*) Pumps should be capable of pumping against a maximum head of 700 ft.

(*d*) The triplex ram pump was the most suitable owing to its simplicity, reliability, and fool-proof character.

(*e*) Oil engines of 7 H.P. and 14 H.P. for light and medium duties respectively should be used.

(*f*) Fuel should be petrol, as more often available than kerosene, or other fuels.

(*g*) Ready-prepared wooden foundations were advisable to facilitate quick erection.

For bore-hole duties the following best answered requirements :—

(*a*) Deep well lift pumps of capacity of 1,000 to 1,500 gallons per hour.

(*b*) Vertical geared frame with crank movement and balance weights for operating pump, designed for 400 ft. lift.

(*c*) 3-H.P. and 7-H.P. horizontal, medium-speed petrol or kerosene engines.

(*d*) For group pumping, 2-in. and 3-in. deep well lift pumps and 7-H.P. engine to drive the operating geared power.

For drive tube wells the following were advised :—

(*a*) $1\frac{1}{2}$-in. and 2-in. tubes with 4-ft. perforated point, brass screened.

(*b*) Pitcher-mouthed pumps with trip, open tops.

(*c*) When coupled in groups any of the above-described surface pumps.

(*d*) 3- or 7-H.P. engines, according to volume and head, if not self-contained sets.

Reciprocating pumps of the direct-driven, steam type are the most popular for general purposes where water has only to be lifted a few feet, and thence driven to a distance or a height. Steam-driven types are compact, light, and easy to mount. The duplex type, which ensures a fairly constant stream of water, is the one generally ordered for stationary steam plants where steam is available, but they are very wasteful in steam consumption, and are liable to give much trouble when they have suffered wear and tear.

The Merryweather fire pump is a compact, portable combination of quick-steaming boiler and fast-running pump that

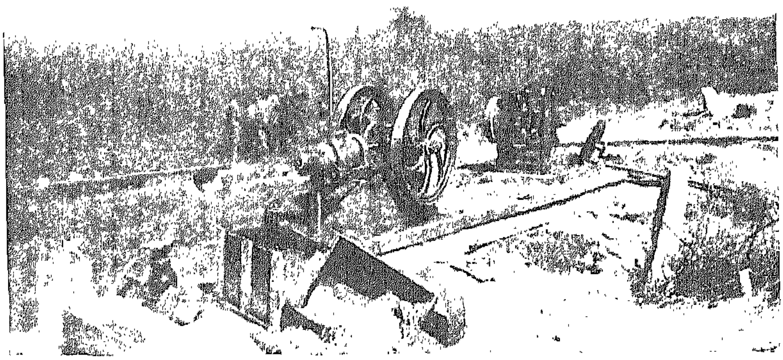


PLATE XL.—ERECTION OF PUMPING INSTALLATION, SALONIKA (LAKE DOIRAN).
7 h.p. oil engine and treble-throw ram-pump for long-distance pumping.

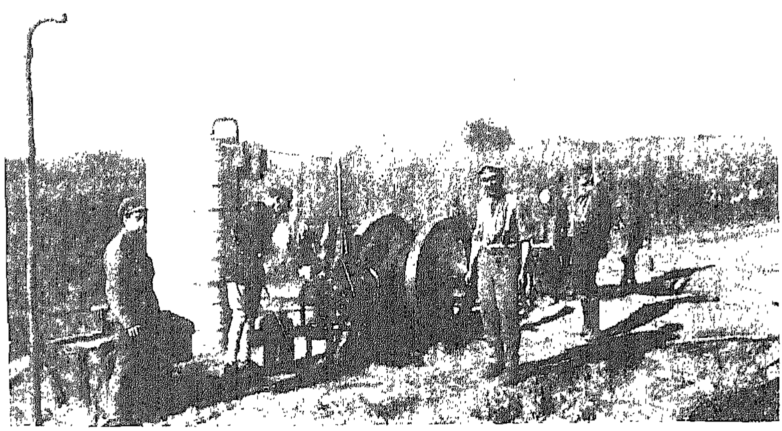


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PLATE XLI.—COMPLETED PUMPING INSTALLATION.
Pumping from tube wells near Lake Doiran and forcing to distant feed tanks.

permits pumping to be started in a remarkably brief space of time, but it is essentially designed for emergencies, and is useful for such duties as those mentioned above. Constant close attention is needed to keep water at a working level, neither too low nor too high, and only good fuel can be used. Pumps of 2,000 to 3,000 gallons per hour capacity, against 300-ft. head were successfully used for rush duties, both for pumping from tube wells and from streams for the watering of men and animals. The photographs attached show the pump in operation (Plates XXXIII and XXXIV, p. 88).

By far the most useful and simple type of pump for other than very light duties is the single-acting ram type, preferably of the triplex variety, to ensure a regular flow of fluid. For small supplies a single or duplex pump is permissible, but the dead centres do not induce that smoothness of running possible by triplex. This type is not dependent upon an enclosed, invisible or inaccessible piston plunger for its functioning, but upon outside-packed rams. They may be direct steam-driven, as in the vertical type, with steam cylinders over the water ends and balancing flywheel to ensure smooth running, or geared for belt, chain or pinion drive from a separate source of power drive if preferred. If a pump is ordered to withstand high pressures it is equally suitable for low-pressure duties, and simply requires a larger or smaller motor. In the ram type the valves are readily accessible, and the working parts are few, in sight, and easily adjustable (see Plates XL and XLI).

The French army employed during the war a single-acting reciprocating plunger pump driven by a petrol engine, mounted on a wheelbarrow, that could be transplanted and worked by a single attendant. For light duties it proved of great value.

Rotary-type pumps have come into increased favour for certain duties on account of their comparative cheapness, lightness, and simplicity. Centrifugal varieties have no equal for raising large volumes against low heads, but they run at high speeds, are quickly damaged by grit, are very inefficient when worn or operating under conditions departing from prescribed conditions. They lose their water readily, and are consequently often difficult to start,

but are cheap. The multi-stage or turbine type of centrifugal has permitted smaller volumes against higher pressures being reached, but there is still the difficulty of handling moderate quantities of water at high pressures, which more nearly approaches customary requirements. For specific duties they can be designed to perform excellent service, but under variable working conditions, such as war usually prescribes, they are less suitable.

Sundry types of drum or screw pumps are on the market and give quite good results when new, but when the internal working surfaces sustain wear they are difficult to start, and the worn parts are troublesome to replace even if they can be renewed. Their cheapness and compactness is an attraction, and they have undoubted merits for emergency duties, but in practice they do not stand up to hard, rough work like other types.

A semi-rotary pump of the Wilcox type gives satisfaction for light hand duties and volumes up to 1,000 gallons per hour. The ancient Archimedian screw, so commonly used in Egypt to-day for the lifting of water a few feet from the irrigation canals to the land, may sometimes be used for lifting water into troughs. This latter has the advantage of no working parts or valves, and it is practically unaffected by dirt or sediment.

A roto-plunge pump of the Revall type has been used, in which a cam on a rotating shaft successively operates several plungers placed radially round its axis. It is too complicated and delicate for general field use.

Amongst the unclassed varieties is the diaphragm pump, an ingenious application of a flexible metallic or rubber disc. These may be single or double acting, and they operate by the buckling of the disc by means of a crank or lever with connection at its centre, which alternatively sucks in and expels fluid that enters through a lower rubber mitre or flap valve. These pumps are very useful for trench clearing purposes, as they will deal with mud, silt, sewage, vegetable refuse, and semi-fluid material in a way approached by no other pump.

The hydraulic ram is the clever adaptation of the water-hammer principle. It consists of a combination of suitably

dimensioned valves within a body fitted with an air chamber. The alternate checking and relief of water pressure caused by a pulsating valve is used to force a certain proportion of the water to a higher elevation than that due to the water head used. The higher the desired height the less the proportion of water delivered, but when there is a surplus of water, this is no concern. An hydraulic ram once properly adjusted for a regular duty will work without attention for

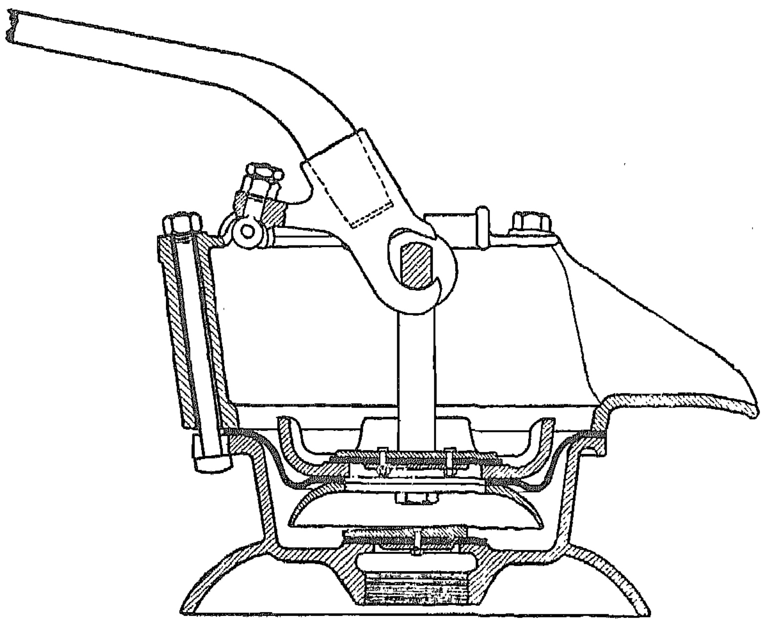

FIG. 47.—Diaphragm pump.

years, provided a constant supply of water is maintained and no grit or extraneous matter is allowed to enter.

The syphon consists of a pipe with two limbs, of which one is longer than the other. As the atmosphere will support a column of water 34 ft. high, the application of a complete vacuum will cause water to rise this height in a pipe. If, therefore, a bent pipe is freed of air and its longer limb is led to a level below that of the immersed shorter limb a constant flow can be set up. It is thus possible to move water over a short obstacle nearly 30 ft. high, provided it can

be led to a point appreciably lower than the original water-level. Syphons can be used for draining bodies of water or emptying vessels, or for leading water from non-flowing artesian wells with a water-level as low as 25 ft. from the surface to land lower than the water-level. The flow of a syphon must be started by filling the whole pipe service with water, thereby replacing all air, or by initiating a movement with a pump. If air finds subsequent admission to the syphon tube the flow will cease.

The Humphrey internal combustion pump was designed to throw large volumes of liquid against low heads. An explosive mixture is fired in a chamber upon the surface of a body of water whose resulting forward movement draws in a new charge of water and a quantity of air. The momentum being absorbed, the water flows back and compresses the air and spent gases whose energy again forces the water forward. A new charge of gas and air is admitted, compressed by the return flow and fired.

Small capacity pumps of this type are made with solid pistons, but they have not acquired popularity.

Pulsometers owe their actuation to the vacuum caused by rapid condensation of steam. Two pear-shaped vessels communicate with a common suction and delivery. When primed with water, steam is admitted to an upper chamber where a ball valve can be thrown on one of two inclined seatings communicating with each water vessel. When the pump is primed, admitted steam enters the open side and expels the enclosed water through a lower delivery valve, but at a certain point of restriction the steam agitates the water and condenses, thus creating a vacuum that sucks over the steam ball valve, and leads to the refilling of the chamber as the contained steam condenses. Small quantities of air are admitted to the water chamber by a sniff valve, which acts as a cushion initially, and partially isolates the steam and water.

Although very valuable for special purposes pulsometers are wasteful in steam, but they are simple, will discharge all kinds of dirty water without much hurt, and can be slung by ropes or set on the ground without foundations or intricate arrangements. There is some-

times the objection that they warm the water slightly. For shaft-sinking operations, when the water is gritty and dirty, or for cleaning ponds or earthworks of fluid, water, or mud, they are specially valuable.

For lifts up to 40 ft. a steam pressure of 30 lbs. per square inch is sufficient ; for 40 to 80 ft. lifts the steam pressure must be increased proportionately up to about 50 lbs. per square inch. Higher pressures enable greater lifts and increased deliveries to be accomplished. A total lift of over 90 ft. is not recommended on economical grounds, and should only be employed under exceptional circumstances.

Steam ejectors or aspirators, sometimes called water guns, owe their property of expelling water to the kinetic energy of escaping steam through restricted orifices. For *boiler-feed purposes injectors are customary, and for* unwatering shafts or trenches they are often used when steam is available.

Air-lift is effected by the aeration and consequent lightening of a column of water in a confined space. Where water is near the surface a slight addition of air some distance down the column will cause the well to flow, but at greater depths there are certain limits beyond which the efficiency falls at a great rate. For satisfactory working it is essential that the air should be admitted at a point that represents a fluid submergence of fully 50 per cent. of the total distance between that point and the surface. Thus, if the working water-level were 100 ft. from the surface, the air admission must be made at a depth of 200 ft., so that if the aquifer was less than 200 ft. deep the well would have to be carried as a sump hole to over 200 ft. to give the necessary submergence. Under these conditions, with suitably proportioned pipes, eleven volumes of air are required per volume of water. The working pressure is that due to submergence, thus 200 ft. submergence would represent $\frac{200 \times 14{\cdot}7}{34} = 86{\cdot}5$ lbs. per square inch ; 100 ft., as above, would represent half that pressure.

The initial or starting pressure exceeds the working pressure partly because an unaerated column has to be expelled before complete aeration is effected, causing a

temporary artificial head, and partly because the static head may exceed the depressed working head. Air may be fed by an internal pipe, and the fluid raised in the annular space between two suitably-proportioned tubes, or air may be forced down the annular space and the liquid removed from the inner.

Obviously air-lifts are only suitable for permanent installations, and their use is usually restricted to special cases where a series of wells are uneconomically distributed, or where air is available, or where coolness or aeration of water is preferable, or where sandy particles badly cut reciprocating pumps or corrosive waters destroy plant. Air-lift is also used in cases where other appliances will not raise sufficient water from a bore-hole of small diameter.

Water may be raised by an air displacement system. A submerged vessel having a lower valve opening inwards can have its contents expelled by the forcing of air on the surface of the water beneath which an eduction pipe leads to the surface of the ground (see Fig. 48). Following the expulsion of an unaerated column of water there is an escape of air and spray; so that if an automatic contrivance is fitted at the surface which shuts off and admits the air supply at regular intervals no attention is required.

Water may be raised from shafts by many primitive appliances almost as cheaply as by modern inventions where labour is cheap or supplies are only intermittently required. Thus water may be drawn from wells in a bucket by means of a windlass. A balanced pole supported on a central fulcrum is still a common way of bucketing water from shallow wells, but in less primitive countries some form of mechanical apparatus is usually employed. The ordinary suction pump is the most common device, but this necessitates occasional removal for repairs.

For irrigation purposes, where animals are generally used for power generation, water is frequently raised by an endless chain to which a series of vessels or jars are attached. As they pass over a surface pulley their contents are emptied, and led away in a chute placed for the water's reception. Sometimes an endless chain fitted with leather or hempen pistons at intervals is made to pass upwards through a pipe

immersed in the water so that a constant flow of water is sustained when the gear is at work.

Another type of well pump consists of an endless helical spring which is carried over a surface pulley, and extends into the water. When put into rapid movement by a surface winch-handle or pulley the clinging water is raised quicker than it can fall back, with the result that it is flung violently outwards by centrifugal force when the direction of the spring is deviated from a vertical direction. These are alleged to be very efficient for low lifts.

Another type depends upon absorption by a belt faced with a thick absorbent nap from which the water is squeezed during its passage between rollers at the surface. Permanent installations for potable supplies demand greater safeguards of purity than the above primitive methods usually allow.

For deep shaft work where a fairly stationary level is maintained at all times it is permissible to install on a platform near the water surface steam or electric-driven pumps of any convenient design, but where there are considerable seasonal variations in level or changes due to static and working conditions it is essential that some form of pump should be installed that will work under

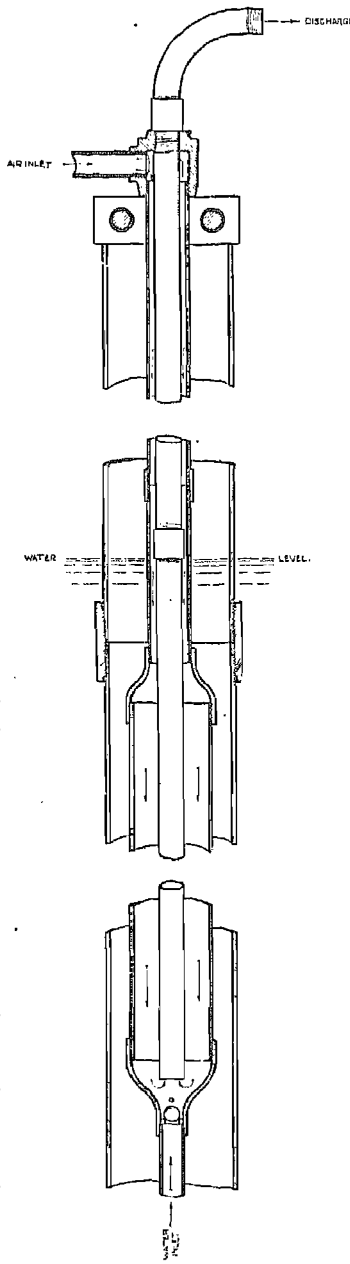

FIG. 48.—Air displacement system.

water. Single, duplex or triplex single, or even double-acting pumps may be fixed, operated by guided rods that extend from overhead cranks to the plungers. Vertically propelled centrifugals may be used in this way submerged.

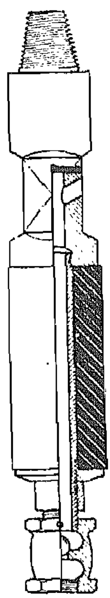

Fig. 49.—Swab.

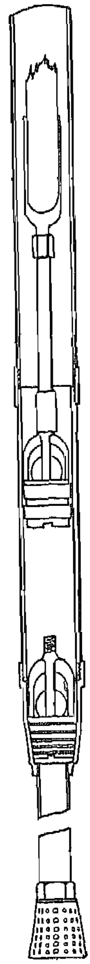

Fig. 50.—Deep well pump.

Bore-holes, usually of from 6-in. to 10-in. diameter, need special water-lifting appliances where the working level of water is beyond the economic reach of a suction pump, say 25 ft. In the absence of other apparatus bore-holes may be bailed with a long cylindrical vessel as that described on p. 115, but this entails the retention of cumbersome appliances at the well mouth, and constant labour charges. Free-yielding bore-holes may likewise be swabbed when very large yields may be possible. Such a well was struck on the Salonika Quay, the water flowing when only a bailer was being raised that did not fit the tubing by nearly 2 inches. A swab is simply a weighted piston with internal valve opening upwards that allows water to pass during its descent, but closes on its ascent, thereby raising the water above it. Raised at a high velocity the slip is proportionately small, and a very large flow of water results.

Usually, however, a more permanent compact and efficient installation is required, and the most obvious is a deep well lift pump. The ordinary deep well pump is a

[*To face p.* 156.

PLATE XLII.—DEEP WELL PUMP WITH STRAINER.

A $4\frac{1}{2}$-inch pump removed from well, showing all perforations as strainer plugged by growth of iron owing to water containing iron in solution.

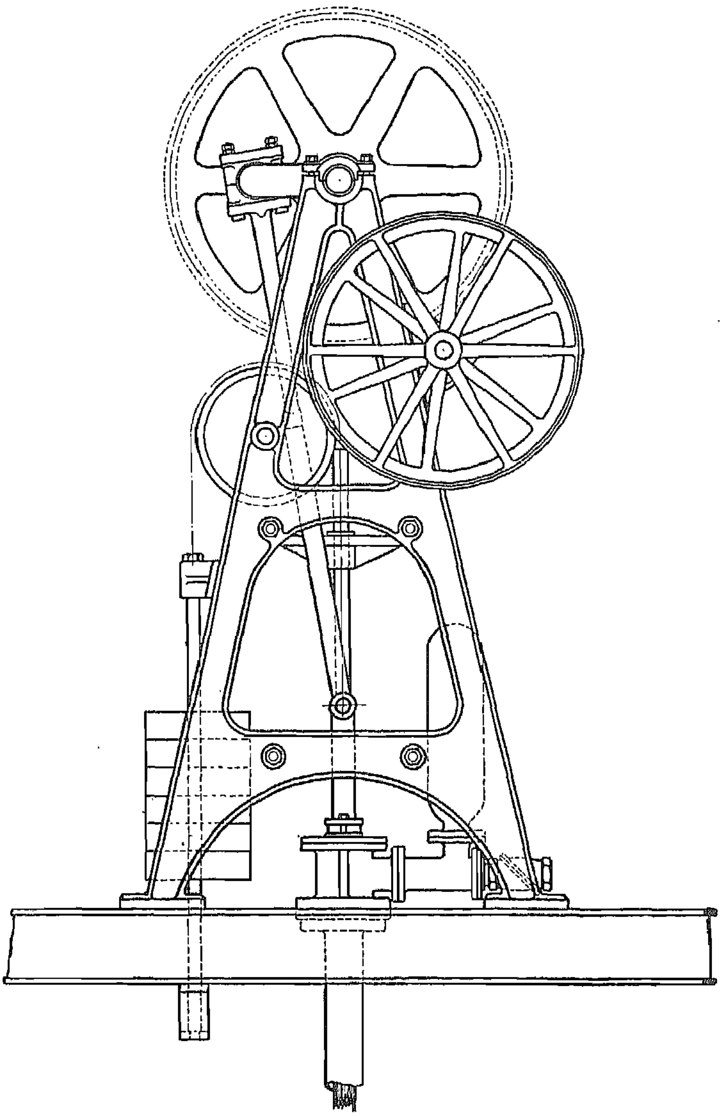

FIG. 51.—Deep well geared pumping frame.

single acting lift pump in which there is a single lower valve and a piston valve on the plunger. Only on the upward stroke is work performed as the cylinder below the plunger fills whilst that above is being lifted. The return journey simply carries the plunger through the liquid it is to raise during the next ascent. It is thus possible to use comparatively light rods, as all the force is tensional with no compression strains, and the whole may be submerged in water, thus allowing for great level variations. A reciprocating motion is imparted to the rods by a crank, beam, or other device at the surface. The pump plunger is packed with hydraulic cup leathers that reduce slip to a minimum under all pressures. With sufficient strength of material it is possible to raise water from a depth of several thousand feet in this way.

The usual surface equipment is a geared-crank frame driven by some motive power. Generally the rods are counter-balanced by weights to reduce the power. Sixteen to twenty strokes a minute are common, although higher speeds can be maintained in emergencies. Frequently a pumphead is fitted at the surface through which a displacement plunger operates on the downward stroke, thereby maintaining a constant surface flow.

As the yield of individual bore-holes is often too small for regional or distant requirements a group of deep wells may be conveniently pumped from a central power station by means of jerker lines. Several such stations proved very successful in Salonika, where large volumes were needed for base camps, hospitals, and army organisations.

Units of ten wells were designed to supply quantities aggregating 5,000 gallons per hour, and although a much larger quantity than 500 gallons per hour might have been obtained from each well, it was deemed expedient to avoid over-pumping in view of the uncertainty of permanence and the importance of continuous supplies. In each case the ten wells were grouped in equilateral triangles with 150 ft. spaces. The pumping power was centrally placed, and driven by a 7-H.P. oil engine, and the radiating jerker lines were supported by pendulums from light standards or allowed to rest in greased notches on wooden uprights.

PLATE XLIII.—GROUP OF TEN WELLS BEING PUMPED FROM CENTRAL POWER BY WIRE JERKER LINES AND PUMPING JACKS FOR SUPPLYING GENERAL HOSPITAL AT KARABURUN, SALONIKA.

Yield, 5,000 gallons per hour.

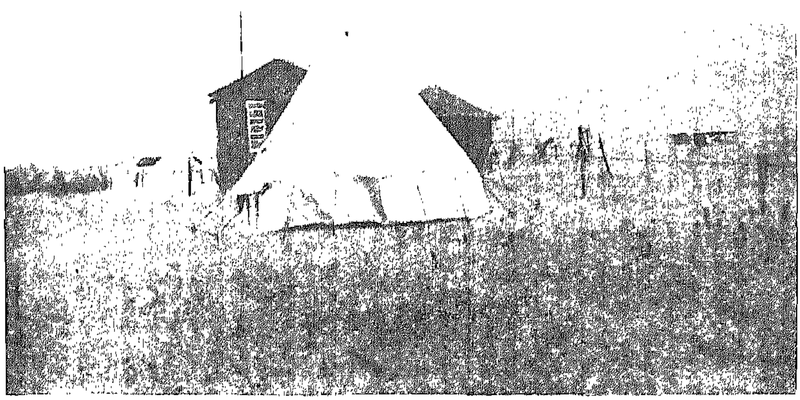

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PLATE XLIV.—GROUP OF TEN WELLS PUMPED FROM CENTRAL POWER BY WIRE JERKER LINES AND JACKS AT DAUTBALI FOR SUPPLYING ORDNANCE AND OTHER CAMPS AT DUDULAR, SALONIKA.

Yield, 5,000 gallons per hour. The sections of these wells are shown in Fig. 9, p. 44.

The pumping jacks were standard steel bell crank devices, as shown in Plate XLIII, designed to transfer the horizontal motion to a vertical as well as to adjust the length of stroke on the pump side. From sixteen to twenty strokes per minute were usual, and the length of stroke was fixed to suit each individual well.

In some cases water was pumped direct to the point of consumption even with a head on the stuffing boxes, but in other cases the preferable procedure was followed of leading the discharges into a central reservoir or tank, from which the water flowed by gravitation or was pumped to its destination. This latter arrangement permits the discharge of each pump to be observed, and enables measurements to be taken. A carefully balanced installation of this class can be run at a surprisingly low cost, and the throwing out of gear of a single well for cup renewals or repair only slightly affects the output.

There are various double-acting deep well pumps on the market which ensure a delivery on the up-and-down stroke. They are only recommendable when the small diameter of the well does not admit of a sufficiently large single-acting pump. The Downey is the most famous of its type, and is operated by direct drive from an overhead steam cylinder. For permanency and high efficiency this steam pump has few competitors, but its complexity and cost are against its use in outlying places, and the increasing use of internal combustion engines favours other types not dependent on steam.

The value of windmills should not be overlooked. For cheaply raising small quantities of water they are very useful wherever there are fairly constant winds. They were satisfactorily used during the war in special cases, and gave little trouble. When dealing with such an uncertainty as wind it is necessary to have sufficient storage to carry over the longest probable windless period. The following figures give details as to the potentialities of windmills :—

TABLE OF SIZES AND DUTIES OF WINDMILLS.

Head in feet.	25	50	75	100	125	150	175	200	250	300	350	400	500
8-FT. MILL—6-IN. STROKE:													
Dia. pump, inches	4	$3\frac{1}{2}$	3	$2\frac{1}{2}$	2	—	—	—	—	—	—	—	—
Galls. per hr. at 30 strokes per min. .	416	318	234	163	104	—	—	—	—	—	—	—	—
10-FT. MILL—6-IN. STROKE:													
Dia. pump, inches	6	4	$3\frac{1}{2}$	3	$2\frac{3}{4}$	$2\frac{1}{2}$	$2\frac{1}{4}$	2	—	—	—	—	—
Galls. per hr. at 30 strokes per min. .	936	416	318	234	197	163	132	104	—	—	—	—	—
12-FT. MILL—8-IN. STROKE:													
Dia. pump, inches	8	5	$4\frac{1}{2}$	$4\frac{1}{4}$	4	$3\frac{1}{2}$	3	$2\frac{3}{4}$	$2\frac{1}{2}$	$2\frac{1}{4}$	2	—	—
Galls. per hr. at 20 strokes per min .	1,479	578	470	411	370	283	209	176	145	118	93	—	—
14-FT. MILL—8-IN. STROKE:													
Dia. pump, inches	12	8	6	$5\frac{1}{2}$	5	$4\frac{1}{2}$	$4\frac{1}{4}$	4	$3\frac{1}{2}$	3	$2\frac{3}{4}$	$2\frac{1}{2}$	2
Galls. per hr. at 20 strokes per min. .	3,300	1,479	833	675	578	470	411	370	283	209	176	145	93
16-FT. MILL—12-IN. STROKE:													
Dia. pump, inches	15	10	8	6	$5\frac{1}{2}$	5	$4\frac{1}{2}$	$4\frac{1}{4}$	4	$3\frac{3}{4}$	$3\frac{1}{2}$	3	$2\frac{1}{2}$
Galls. per hr. at 15 strokes per min. .	5,816	2,601	1,664	937	760	650	526	471	416	363	318	234	163
18-FT. MILL—12-IN. STROKE:													
Dia. pump, inches	18	12	10	8	7	6	$5\frac{1}{2}$	5	$4\frac{1}{2}$	4	$3\frac{3}{4}$	$3\frac{1}{2}$	3
Galls. per hr. at 15 strokes per min. .	8,000	3,745	2,601	1,664	1,374	937	760	650	526	416	363	318	234

The above figures are based on a wind velocity of 12 miles per hour, and are given for the "Climax" Windmill.

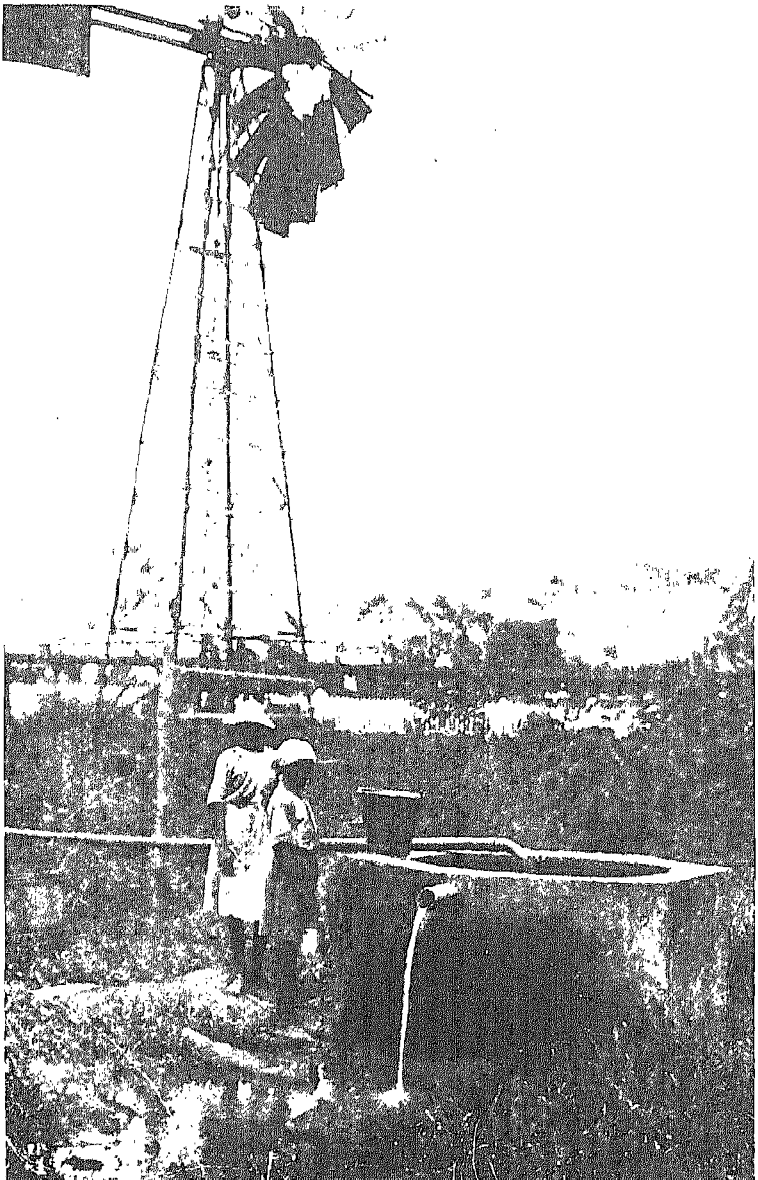

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PLATE XLV.—WINDMILL.

Windmills are usually governed in such a way that excessively high winds entirely or partially throw the mill out of operation.

Automatic governing is secured by setting the wind wheel slightly out of centre, whilst the tail is truly centred. This induces a tendency to fold the tail and force the wheel to present its edge to the wind; an inclination that is prevented by a spring or weight that keeps the tail or vane at right angles in all but excessive winds. The spring is so adjusted that a high wind velocity partially or entirely forces the tailpiece in a position more horizontal to the wind wheel, and so causes the wheel to face the wind at an angle, and leads to a reduction of speed.

Notes on the Character of Waters.—All ground waters contain mineral or organic substances in solution, and the extent of their contamination determines their value as sources of supply for potable, irrigation, or other purposes. Even rain water is rarely free from dissolved or suspended impurities, as in its descent gases are absorbed from the atmosphere and particles of dust adhere. Water possesses such potent solution properties, and so readily combines with other substances, that short contact with rocks of almost any kind or age leads to its mineralisation more or less.

Before acceptance for potable purposes waters are usually subjected to analysis with a view to ascertaining whether they contain substances which in quality or quantity are likely to be injurious to health. Within populated districts where sewage contamination is possible, special search is made for contents which might suggest pollution, and it is now usual to make a bacteriological examination to ascertain whether pathogenic (disease-carrying) germs are present.

Waters may, according to circumstances, require a physical, chemical, biological, or bacteriological examination, and any one of these may alone be decisive as to the *unsuitability* of a water for potable purposes in its then condition. It is quite unlikely that all will be required in any case.

The chemical examination may be comparatively simple or more elaborate, according to the use to which the water is to be put.

Physical Examination.—The physical examination of a

water is a comparatively simple matter, merely involving such features as appearance, odour, taste, and amount and character of the sediment; the interpretation, however, requires thought.

Appearance.—A clear, sparkling water without noticeable colour gives a good impression but must not be relied upon as an indication of purity.

Floating matter that will readily settle or can be filtered out may leave the water quite satisfactory.

Turbidity that is lasting and cannot be completely filtered out is a suspicious characteristic, though in a newly made well or recently developed water source it may be a feature that will right itself after a time, being due to very finely divided mineral matter. Turbidity, due to the oxidation of iron (ferrous) compounds, may be eliminated by aeration and sedimentation or require treatment to expedite it.

Colour, when not obvious, may usually be disregarded. Yellowish waters mostly contain a fair amount of organic matter, probably sewage; and peaty waters may be quite red-brown. In either case, the actual cause of the colour will probably be determined by the chemist, but its remedy may require the aid of the sanitary inspector or the geologist, or both.

Odour.—This is a very simple test, and should not be neglected where a water is under suspicion. It is generally carried out by warming some of the water in a closed vessel to a temperature of about 65° C. The interpretation of the cause of the odour may, or may not, be easy.

An odour of sulphuretted hydrogen in the cold from freshly drawn water is likely to be due to chemical changes in the rock from which it comes, but then the odour is likely to pass off very soon in the air, and may leave the water quite good; or the sulphuretted hydrogen may be a product of the reduction of sulphates by bacterial action, in which case it would be a bad feature.

Taste.—All waters with an odour are likely to be credited with a taste, as the two sensations are intimately associated. A good water should have no taste that can be described, though freshness or briskness due to gas (carbonic acid

gas) or flatness due to the absence of gases (as in distilled water) are readily recognised.

Peaty waters have a taste. Chalybeate waters have an inky taste due to an iron salt, which taste can be detected by some with as little as 0·2 grain per gallon of iron in solution.

Certain other mineral salts may give a taste to water, but the most likely one is sodium chloride (common salt), the detection of which different people are variably susceptible to. There is probably no harm in a water containing salt up to the limit at which it is decidedly objectionable. The writer has used, and seen used, brackish waters on the objectionable side without any observable influence on general health.

Chemists do not look upon it as part of their duty to taste the water submitted to them for analysis; any obervations made on this matter should, however, be submitted to them.

Sediment.—In a preliminary examination of a water it will generally be noticed whether there is much or little sediment on standing, and if much its specific character may lead to useful information with regard to the water source. It may be entirely mineral or partly organic, in which latter case a biological examination should be made.

Chemical Examination.—A chemical examination of a water may include a preliminary test for alkalinity or acidity: normally it includes an estimation of the amount of each of the following constituents:—

Substances or characters likely to be of organic origin:

Free ammonia. Albuminoid ammonia. Total oxygen consumed in a certain time. Nitrogen as nitrates (and perhaps nitrites).	These, together with chlorine, are the best indicators of sewage pollution.

Inorganic substances:

Chlorine.
Hardness, total (temporary and permanent).
Solid residue on evaporation.

For special purposes:

Estimation of the quantity of each inorganic constituent of the solid residue—especially calcium and magnesium compounds and the chlorides, carbonates, sulphates and nitrates of these, and the alkalies (sodium, and perhaps potassium).

Iron may want estimating.

Other metals of a harmful kind may require to be looked for in exceptional cases.

A few notes under each head are herewith appended:

Alkalinity.—Most good waters are slightly alkaline owing to the presence of bicarbonate of lime (or, maybe, carbonate of soda), but if the water is strongly alkaline it is a suspicious characteristic and may be due to ammonium compound derived from sewage, but this will be determined in other ways.

Acidity is a bad sign in a water, because it indicates a capacity to dissolve lead, iron, or zinc, some, or all, of which metals may be found in a water-supply system. Acidity in waters may be due to organic acids derived from peat, or from swamps or a vegetable soil; or to discharge of waste waters from factories; or to free carbonic acid gas in a very soft water.

There should be at least 3 or 4 degrees of hardness in a water or an alkalinity, the chemical equivalent of this to ensure the water not attacking metals. Limestone, lime, or lime water are the best antidotes for acidity.

Free ammonia, so-called, is ammonia that is freely liberated with the steam on boiling the water, and is estimated in the condensed steam or distillate. Alone it is not injurious, and alone it cannot be permitted to condemn a water even when excessive, since there are other possible sources of it (or reactions producing it) than sewage.

Albuminoid ammonia is the name given to the ammonia which is given off on distilling a water, already freed from free ammonia, with a strong oxidizing agent, usually permanganate of potash in a strong solution of caustic potash. This ammonia is derived from organic matter containing nitrogen.

The interpretation to be put upon the analytical results

of free and albuminoid ammonia cannot be dissociated from that of chlorine, as will be perceived by the following generally accepted maxims :—

(1) Much albuminoid with much free ammonia and chlorine points distinctly to sewage pollution.

(2) Much albuminoid ammonia with little free ammonia and little chlorine points to vegetable contamination.

Much and little are relative terms to which no definite figure can be given, but some analytical chemists would absolutely condemn a water for domestic use that contained 0·15 part per million of albuminoid ammonia, even if free ammonia were absent. Since the albuminoid ammonia is commonly the source of the free, they are likely to vary inversely as each other, and the combined yield must be considered in passing or condemning a water. (See, also, remarks under Total Oxygen Absorbed.)

Total Oxygen Absorbed.—The amount of oxygen absorbed by a water from potassium permanganate in an acid solution in a given time is, or may be, made a rough measure of the organic impurity in the water. Under some circumstances, the weight of the oxygen absorbed is considered to be a close approximation to the weight of organic matter in the water. In the majority of cases, however, the most that can be said is that the organic matter in the water is proportional to the oxygen consumed, when interfering constituents are absent.

The process is carried out at a temperature of about 80° F., and the time usually allowed is 4 hours, though bad waters require more, and notwithstanding many *possible* sources of error due to other constituents in the water which also absorb oxygen, such as nitrites, ferrous compounds, and sulphur compounds, if conducted under exactly the same conditions it is a useful source of information as to the organic contents of the water.

Nitrogen—Nitrates and Nitrites.—Nitrates may be harmless oxygenated products of organic nitrogenous matter, and as such be indicative of previous sewage contamination, but they may not bear this interpretation, as there are other possible sources of these salts, and chlorine may be more decisive on this point than the nitrates.

Nitrites are scarcely worth separately estimating, for they are essentially transition products of ammonia changing to nitrates under aerobic bacterial action or conversely nitrates changing to ammonia under anaerobic bacterial action. Still, the presence of nitrites may be considered as evidence of changes then going on, and so inferentially of near or recent organic pollution or other undesirable condition.

Chlorine.—The estimation of chlorine by a standard solution of nitrate of silver is one of the easiest and most useful tests to apply to a water. Chlorine does not exist free in water, or indeed anywhere in Nature, but always in the form of chlorides, of which sodium chloride (common salt) is by far the most common. A point of importance is that whatever form the chloride may take in a water the chlorine itself never loses its identity to the nitrate of silver test. Chlorides are not removed by filtration simply, nor changed by bacterial action like organic matter. The actual amount of chlorine in a water, if due to common salt, is itself immaterial unless in great excess.

Chloride of sodium constitutes upwards of 1 per cent. of urine, hence chlorine is always abundant in sewage; so absence of chlorine, or say less than 1 or 2 grains per gallon, stamps a water as probably quite free from sewage contamination; but the converse of this does not apply, as there are other sources of chlorine, and some rocks contain much common salt which will be dissolved by passing water. Even sea spray may be largely responsible for chlorine in water near the coast.

Much chlorine with much ammonia and oxygen absorbed distinctly points to considerable and near contamination. Much chlorine with little ammonia and oxygen absorbed indicates either a rock source, or distant contamination, or efficient filtration.

It is remarkable how rapidly organic matter sometimes disappears from a water on passing through a soil or filter where the proper biological conditions prevail, so that where chlorine is large without obvious reasons for being so, the estimation of nitrates may come in useful to decide its probable source.

Hardness in a water is usually estimated by its power to

destroy a certain amount of soap solution of a certain strength, and in a potable water is due to the presence of salts of calcium and magnesium.

The hardness is often expressed in degrees, but since this tells nothing about the composition of the salts causing it, it is just as well expressed in grains per gallon (like the other contents) of a definite substance to which it is equivalent, say calcium carbonate. Under 5° (or grains per gallon) would be very soft, 5° to 20° would range through fairly soft to moderately hard, above 20° hard to very hard.

Soft waters are best for some domestic purposes, and for steam boilers, but it is generally thought that a moderately hard water is best from a hygienic point of view, and certainly some very hard waters are drunk with impunity, but if magnesium salts preponderate, such as magnesium sulphate (Epsom salts) naturally the water is unsuitable.

Temporary hardness, due to bicarbonates of lime or magnesia, can be got rid of by boiling the water, which operation liberates the carbonic acid holding the carbonates in solution. The addition of lime in proper quantity also reduces hardness by taking up the carbonic acid and forming insoluble carbonate of lime which is precipitated with the other carbonates.

Permanent hardness, due to sulphates or chlorides of calcium and magnesium, is so called because it cannot be got rid of without introducing, or, rather, producing substances more objectionable from a hygienic point of view. Such waters can be properly softened for boiler purposes.

Solid Residue.—On evaporation of a water to dryness in a suitable dish on a water-bath, the various inorganic substances previously dissolved in the water will be left, and can be weighed. For complete desiccation, and to get rid of water of crystallisation, it is usual to heat the dish containing the solids to a temperature of about 180° C.

In a good water the residue obtained should be white; if it is brown or reddish doubtless it contains iron; if yellowish, organic matter is very probable. If on more strongly heating the residue blackens organic matter is proved, and if the odour is particularly disagreeable the organic matter is probably of animal origin.

An analytical chemist can often derive useful information as to the chemical character of the solid residue by merely an ocular examination, perhaps with a lens, more particularly before heating to the higher temperature; the addition of a little hydrochloric acid will show if carbonates are present and abundant or absent.

Various other points might be involved in an elaborate analysis, but are not appropriate here.

The amount of solid residue to be permitted in a drinking water cannot be arbitrarily started, as so much depends upon its composition, but providing there is no definitely harmful constituent and that the magnesium compounds and sulphate of sodium are not themselves excessive, solid residue which can only be described as excessive may be harmless in a drinking water. In some desiccated regions waters containing 0·001 per cent. (70 grains per gallon) are regularly used.

In the case of a newly-made well tapping a stagnant water source the solid residue may reach 250 grains per gallon, but if a circulation can be established by pumping, improvement is almost certain. Various wells in the writer's experience have gone through this process, and been used without known harm long before a chemist dare pronounce them as safe.

Spa waters, or mineral springs with medicinal properties, are more or less of this character, but permanently mineralised.

Natural Evidences of Composition of Solid Residue.—Sometimes the main or the special constituents of the inorganic salts dissolved in a water will become evident by mere exposure of the water to the atmosphere.

Silica is very likely to be deposited around hot springs, also other substances that are more soluble in hot than cold water.

Calcium carbonate in the form of a light porous limestone, called calcareous tufa, is a fairly common substance to find around springs or in water-courses where the water has passed through calcareous strata. These so-called petrifying springs lose carbonic acid on exposure to the air, particularly if sprayed, or passing over growing vegetation,

and deposit the carbonate of lime (calcium carbonate) previously held in solution by them.

Efflorescences of various salts occur on soils or rocks where an upward capillary circulation of water develops owing to great or continued surface evaporation. Some of these efflorescences are of commercial importance.

Chalybeate waters are practically always characterised by an irridescent oily-looking film on their surface, or at a spring by ferruginous, red-stained surroundings. Since a soluble salt of iron with tannic acid forms ink, an easy test for iron in a water is made by adding brandy (or any alcoholic liquor matured in oak casks). Even dead leaves in a running stream may become blackened from the same cause; or two streams coming respectively from rocky and swampy regions may on meeting develop a dark colour from the same reason—iron and tannic acid.

A sewage polluted stream and a chalybeate one may mutually compromise each other by the development of blackness, in this case, however, due to the sulphuretted hydrogen in the sewage stream combining with iron in the other to form sulphide of iron.

Iron in a water is objectionable, not so much from a hygienic point of view as that it is liable to cause iron-mould in articles during washing; it is inimical to certain manufacturing purposes, and if above a certain small amount and the water also contains some organic matter, the algæ *crenothrix* is likely to grow to such an extent as to largely or completely block the pipes carrying the water. The iron may indeed be obtained from the pipes themselves. A water containing crenothrix, too, is likely to have a bad odour.

Chemical Evidence of the Composition of the Solid Residue.—For certain trade purposes, such as brewing, tanning, dyeing, etc., and for steam boilers, it is necessary or advisable to know all about the composition of the substances dissolved in the water available, for which purpose there is made a quantitative analysis to determine the quantity of the various acid and basic radicles present. Afterwards the acids and bases are theoretically combined to form salt in such a way as the analytical chemist thinks they

most likely occurred in the original water; but the number of possible combinations is always greater than he is able to express quantitatively or qualitatively with certainty, owing mainly to interactions between the salts themselves, and because the solubility of each substance is modified by the presence and quantity of others in the same solution.

It is believed that substances are more or less dissociated when dissolved in water, that is to say, liberated as free positive or negative constituents called "ions," which travel in opposite directions under electrolytic action, of which the metal itself is one and the acid with which it is combined the other, so in place of stating results of analysis in basic and acid radicles as CaO and CO_2, it is fairly common now to state them in ions, as Ca and CO_3, which is actually more convenient for the preparation of compositions. These should be given in a report of an analysis so that possible errors in combining them may be corrected by observation of the behaviour of the water, and the water composition can be understood by other chemists.

Incidentally it may be mentioned that calcium is the dominating metal in most waters and magnesium the most disturbing and possibly injurious one.

Biological Examination.—The biological examination is here taken to mean the low-power microscopic examination of a water or water sediment for the detection and identification of the various organisms in it, living or dead, such as aquatic insects, worms and infusoria generally, together with algæ, moulds, cellular tissue, hairs or fibres of plants, and fæcal debris. The above will, of course, only be found in an unfiltered or imperfectly filtered water; still, they may give useful information as to the probable source of the water or the pollution to which it is exposed, perhaps from a badly constructed or badly protected well. This examination may furnish, or be specially adapted to ascertain, the cause of bad odours in waters.

Bacteriological Examination.—With the exception of poisonous metals the chemical examination of a water usually detects nothing that is itself likely to be particularly harmful in the moderate quantity present, even in bad

waters; it merely points significantly to conditions which are dangerous. It may, however, justify an absolute condemnation of the water for domestic use; or it may fail to justify an unqualified good report. Here it is that a bacteriological examination is so useful and probably essential.

The real danger in polluted waters lies in the presence of minute organisms which are the carriers of specific disease infection—plants actually in a general way called bacteria. These bacteria are not dissolved in water like most of the chemical substances spoken of, but are actual solid bodies which float and can be filtered out with adequate precautions. Though not the chemical products of bacterial action, the so-called *toxins* are the real poisonous substances, at least, in most cases. However, if the bacteria are eliminated the products of their action will cease to be formed.

Unfortunately a bacteriological examination cannot be carried out quickly, and the processes and interpretations require the services of an expert in this particular department of water examination, all of which considerations depreciate its value for emergency water supplies, and enhance the value of simple sterilisation processes.

Reports on Water Analyses.—Reports on samples of water by different chemists differ greatly, partly due to individual ideas on the relative importance of various constituents or knowledge of the particular use to which the water will be put. Again, chemists differ in the matter of the numerical statement of the results; some give grains per gallon, some parts per 100,000, others parts per 1,000,000 for the organic constituents, and grains per gallon for the remainder. The tendency now is to give everything in parts per 100,000 as a kind of compromise.

A TYPE ANALYSIS

No chemist at any time would be likely to give all the particulars enumerated below. The water is supposed to be fairly good, but not high class.

To convert grains per gallon into parts per 100,000 divide by 0·7
,, ,, ,, ,, ,, 1,000,000 ,, 0·07
,, parts per 100,000 into grains per gallon multiply by 7.
,, ,, ,, ,, parts per 1,000,000 ,, 10

Characters observed.	Result.
Appearance	Clear and bright.
Colour	None.
Odour in the cold	None.
Odour at 65° C. (150° F.)	Slight, not specifically identifiable.
Reaction	Faintly alkaline.
Sediment	Small—inorganic.

Substances estimated.	Grains per gallon = parts per 70,000.	Parts per 100,000.	Parts per 1,000,000.
Free or saline ammonia	0·003	0·004	0·040
Albuminoid ammonia	0·004	0·005	0·050
Oxygen absorbed in 15 min. at 80° F.	—	—	—
Oxygen absorbed in 4 hours at 80° F.	0·210	0·300	3.000
			Remarks.
Chlorine	3·0	4·3	=to common salt 4·95 and 7·09
Nitric acid as nitrates	1·0	1·4	—
Nitrous acid as nitrites	None.	None.	—
Nitrogen in nitrates and nitrites	0·2	0·3	—
Total hardness (soap test)	20·0	28·5	—
Temporary hardness	16·0	22·9	—
Permanent hardness	4·0	5·7	—
Total solid residue	30·0	43·0	—

Composition of the solid residue, per cent. :—

Metals : Iron (Fe), aluminium (Al), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K).

Acids : Carbonic (CO_3), sulphuric (SO_4), hydrochloric (Cl), nitric (NO_3), silicic (SiO_3).

Other metals may be specially tested for.

The composition will then be shown as silica, alumina, and ferric oxide not united with acids as too uncertain; then calcium carbonate, sulphate, chloride, and nitrate; magnesium carbonate, sulphate and chloride; sodium carbonate, sulphate, chloride or nitrate; and potassium chloride, organic matter and loss, according to the opinion of the chemist as to the compounds preferentially formed and the supply of constituents for them.

Water Purification.—Water purification in the fullest sense would include all devices adopted to exclude or eliminate such objectionable impurities as have been alluded to in the preceding pages, which is quite beyond the

intended scope of these "Notes on the Characters of Waters," so only a few general hints are given on some of the more easily adopted methods.

It should not be overlooked that the dangers of pollution or contamination are not confined to the actual source of the water, but continue throughout the whole process of distribution in tanks, carts, and water vessels of other kinds; and suspicious or really dangerous conditions or surroundings are little appreciated or even troubled about by fatigued and thirsty troops.

Detached units or individuals thrown upon their own resources in nearly waterless regions may sometimes render muddy, badly-fouled surface waters comparatively safe by simple means. Foul-smelling, cloudy waters may be greatly improved by agitation in a vessel with clay and then decanting after settlement. Accelerated sedimentation and partial purification may be effected by the addition of alum, which produces a coagulant that also carries down bacteria. Organic matter may be oxidised and the water improved by a discreet use of Condy's fluid (permanganate of potash).

Filtration through sand is the standard method of purifying water on a large scale, and it can often be carried out with advantage on a small scale by improvised methods with material and utensils at hand in out-of-the-way places. Small sand and charcoal filters and unglazed earthenware or stone jars are all good for domestic purposes if properly attended to, which quite often is not the case.

Lime treatment used as for water softening improves the water in other respects; by chemically hastening the removal of iron if present, and by forming a precipitate which carries down any insoluble matter, including bacteria.

Sterilisation.—In the rapid movement of troops from place to place, with available waters of unknown purity, and more still in the concentration of large bodies of troops for a time in a restricted area with very primitive sanitary arrangements, water contamination is a likely, serious contingency, and none of the ordinary large scale permanent methods of purification can be adopted. This during the late war led to the adoption of a rapid method of sterilising

water by means of chlorinated lime (bleaching powder). Judiciously conducted chlorination does not render the water objectionable, but sometimes an excess of that required for sterilisation is carelessly or intentionally added, creating discontent and a general condemnation of the process.

Chlorination has become a general method of sterilising doubtful and impure waters, chlorine itself being often used for the purpose.

Boiler Waters.—Providing there is an absence of acidity, a clear soft water is best for boiler, as for many other purposes; but more commonly the suitability of a water for boiler use has to be determined by the quantity and chemical character of the solid residue left on evaporation. Condensed water often causes pitting on boilers, and rain water and pond water often lead to excessive priming. A hard water necessarily gives a large solid residue, the chemical character of which should be examined.

Magnesium and calcium chlorides are particularly bad constituents, because at a high temperature they decompose yielding free hydrochloric acid, which pits the boiler plates.

Permanent hardness is likely to be due in the main to sulphate of calcium, which being less soluble in strongly heated water than cold and because of concentration is particularly liable to form a hard crust or scale; such scale is not only difficult to remove, and the more so if the water also contained clayey matter, but it leads to waste of fuel and fall in output of the boiler. This can be prevented by special treatment of the water.

Temporary hardness is due to the carbonates of calcium and magnesium which also are deposited on boiling the water, but the deposit is more powdery and not so hard and difficult to remove as the sulphate deposits; moreover, it can be almost entirely removed from the water before introduction into the boiler by any one of the various water-softening plants.

Soft waters with a large solid residue are due to carbonates of the alkalies, sodium more particularly, and produce a soft deposit, which, like the other carbonates, can be easily removed by "blowing off."

Besides these main constituents that must be considered

excess of chlorides, say sodium chloride (common salt) in a water renders it liable to corrode brass fittings and be injurious where a voltaic action can be set up between metals or a metal and its impurities.

Nitrates are likely to be too small to materially affect the water for boiler purposes, but in large amounts they are undoubtedly injurious to boilers.

Attached are a few analyses of typical waters illustrating customary features.

ANALYSIS OF BORE-HOLE WATERS.

Parts per 100,000.

Contents.	110′ sand.	500′ chalk.	100′ sand.	348′ sand below clay.	144′ oolite.	168′ clay.	254′ chalk.
Total solids . .	10·0	148·6	25·7	32·8	61·4	130·0	142·8
Chlorine . .	1·7	73·1	6·3	2·3	2·6	10·7	51·3
Ammonia, free .	0·0004	0·20	0·033	0·0164	0·0064	0·181	0·114
Ammonia, albuminoid . .	0·0010	trace.	nil.	nil.	nil.	trace.	0·0004
Nitrogen, nitrates.	0·074	0·28	nil.	trace.	nil.	trace.	nil.
Nitrogen, nitrites .	nil.	trace.	nil.	nil.	nil.	nil.	nil.
Hardness, total ·	3·8	39·1	12·3	1·0	36·0	23·3	38·8
Hardness, temporary . .	—	—	—	—	—	—	20·3
Hardness, permanent . .	—	—	—	—	—	—	18·6

ANALYSIS OF SPRING WATERS.

Parts per 100,000.

Contents.	Green sand.	Portland beds.	Chalk.	Polluted water.	Land drain sp.	Moorland gathering.	Thanet sands.
Total solids . .	14·0	38·8	29·9	154·7	27·0	15·5	30·04
Chlorine . .	1·2	1·4	1·4	27·5	3·9	2·6	3·40
Ammonia, free .	0·0003	0·0014	—	0·001	0·001	0·001	0·001
Ammonia, albuminoid . .	0·0001	0·004	—		0·0055	0·0015	0·0031
Nitrates . .	0·497	0·640	0·274	1·395	—	—	1·33
Nitrites . .	—	—			nil.	nil.	—
Oxygen absorbed in 3 hours .	0·014	—	—	—	0·036	0·032	0·046
Hardness, total .	—	32·3	24·5	53·0	9·3	9·0	18·4
Hardness, temporary . .	—	—	20·9	18·9	4·3	—	—
Hardness, permanent . .	—	—	3·6	34·1	—	—	9·4

As indicative of the progressive mineralisation of water draining from mountains into an arid delta may be given the attached analyses of waters, flowing first above ground and then below, from the interior station of Zaida to the coastal region of Sheik Othman, where the British Forces were stationed to protect Aden in the Lahej delta.

Parts per 100,000.

Contents.	Zaida.	Lahej.	Bir Ahmed.	Dhebic Well.	Saline Hamish.	Sheik Othman.
Total solids . .	73·0	164·0	280·0	235·0	346·0	570
Chlorine . . .	14·5	29·2	78·0	75·0	153·0	170
Sulphates . . .	18·1	54·9	70·9	65·0	50·9	174
Total hardness . .	24·2	56·5	32·5	85·0	150·0	171
Temporary hardness .	13·2	16·5	14·0	4·0	13·0	?
Magnesium sulphate .	4·6	38·5	33·9	27·58	19·35	?
Sodium sulphate . .	21·3	35·8	?	?	?	?
Magnesium chloride .	nil.	nil.	70·0	nil.	92·11	?

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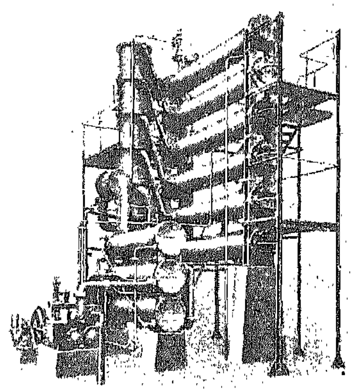
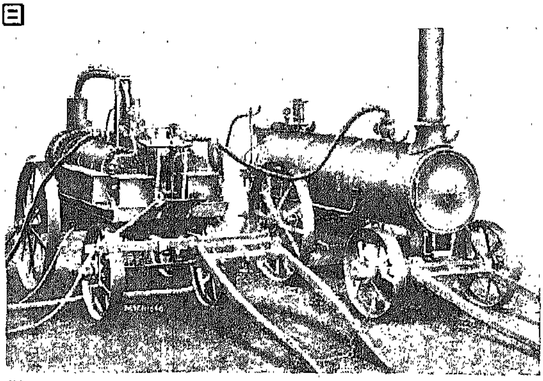


Fresh Water Distilling Plant

For the production of fresh water from the sea or other impure source.



Portable Distiller.

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